1) Bias of North American Mesocale (NAM) Model Forecasts of Summer Rainfall over Central U.S., and

2) Impact of FORMOSAT-3/COSMIC Observations on Global Forecast System (GFS) Predictions in the Northern Hemisphere

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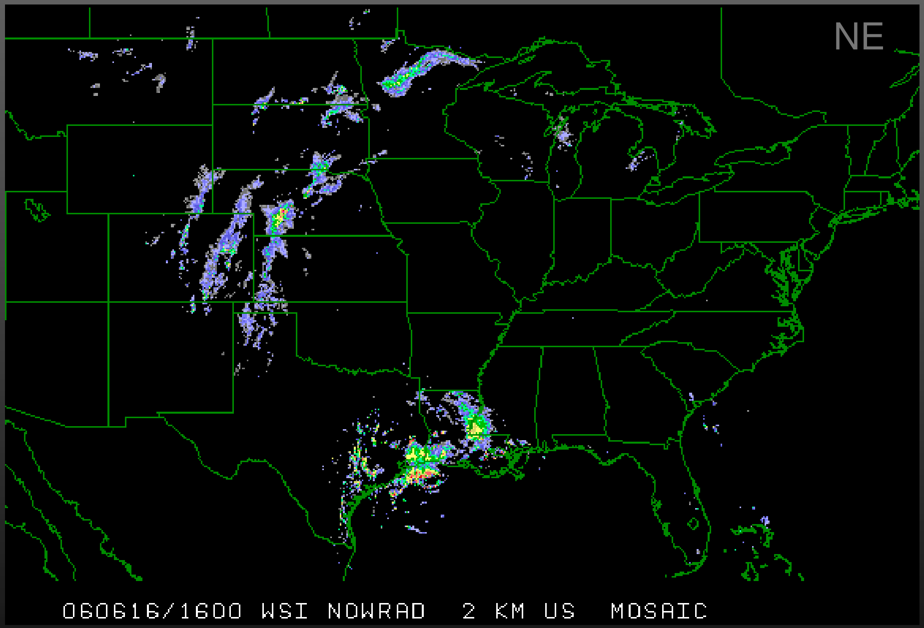
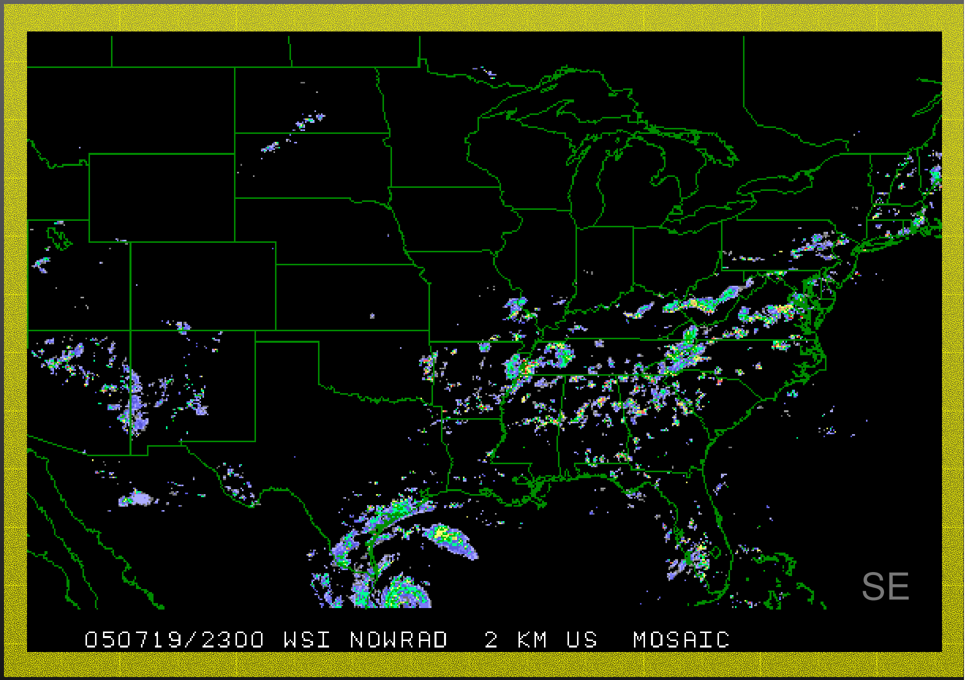
1) **Bias of North American Mesocale (NAM) Model Forecasts of Summer Rainfall over Central U.S.**

– **Role of midtropospheric perturbations**

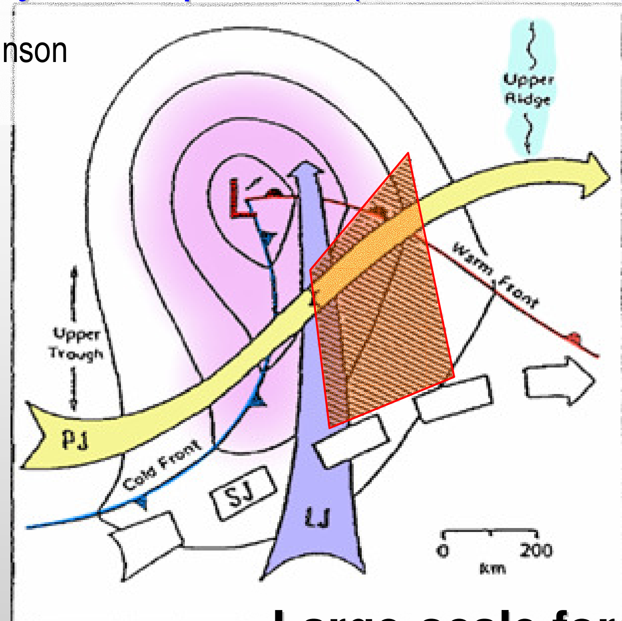




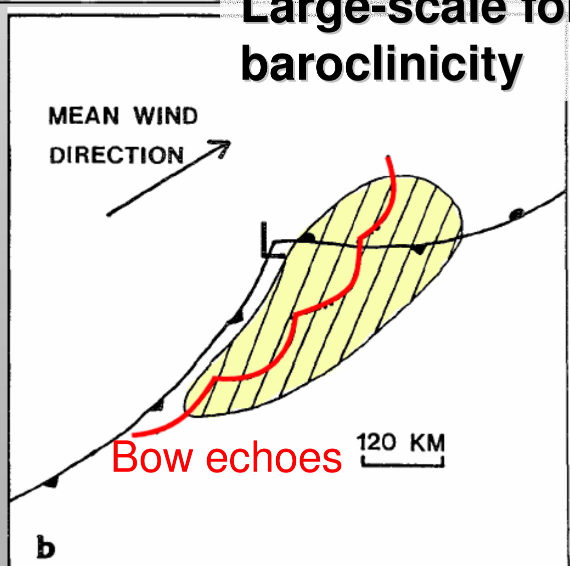
Synoptic conditions for organized convective storms

Dynamic pattern (cold-season)

Uccellini & Johnson (1979)

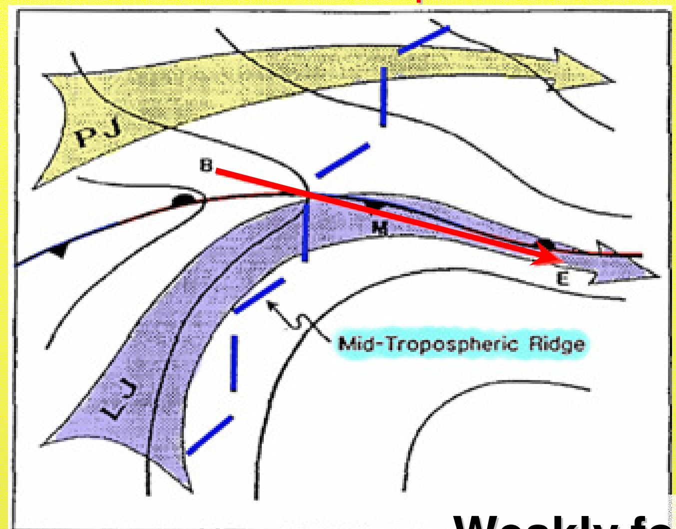


Large-scale forcing/ baroclinicity

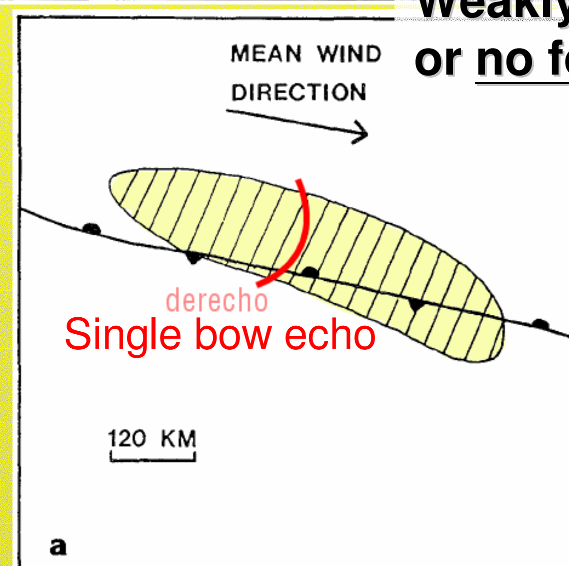


(Johns 1993)

Warm season pattern



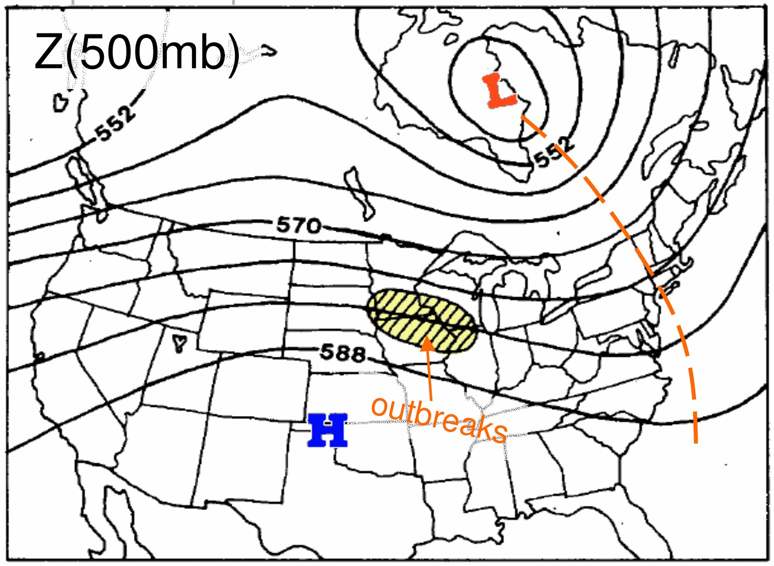
Weakly forced or no forcing



Northwest Flow Severe Weather Outbreaks (NWF outbreaks)

(Johns 1982)

composite flow pattern



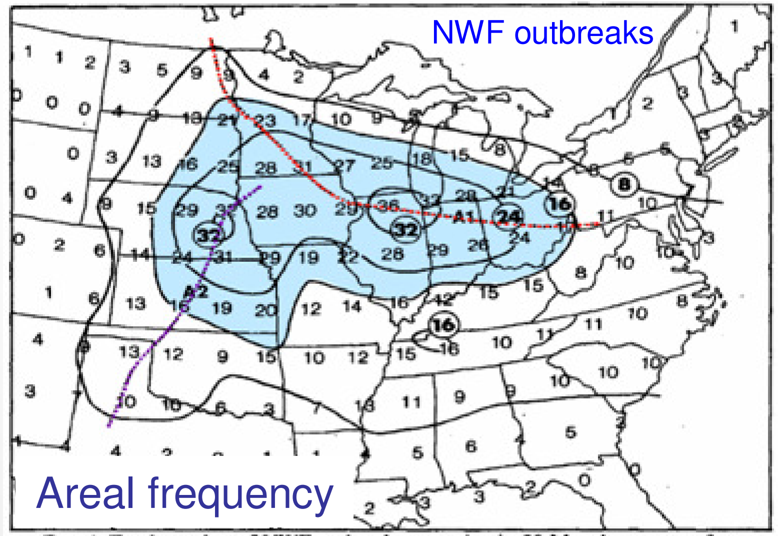
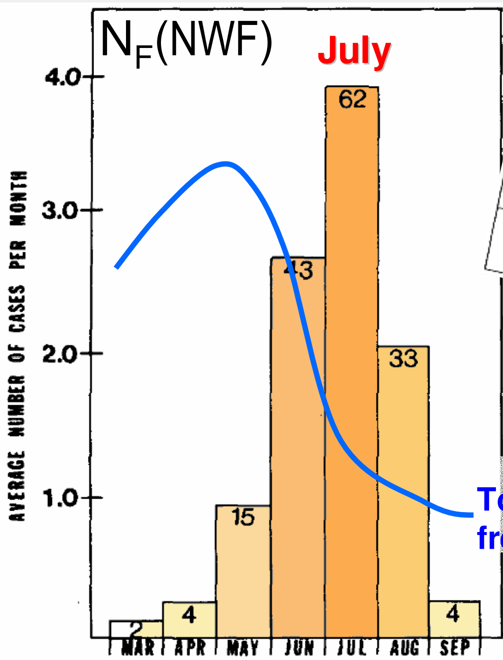
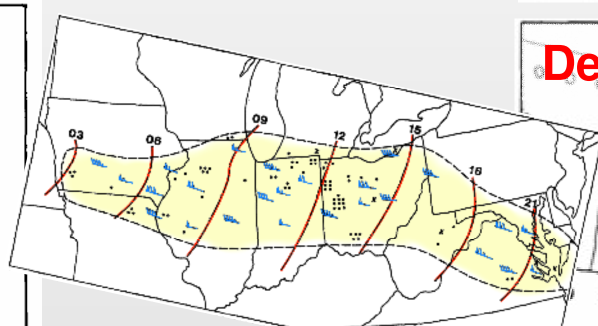
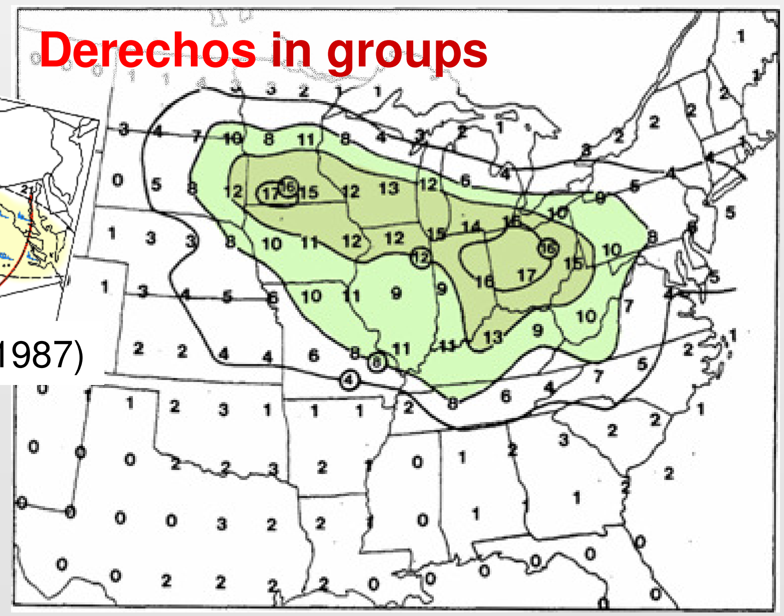


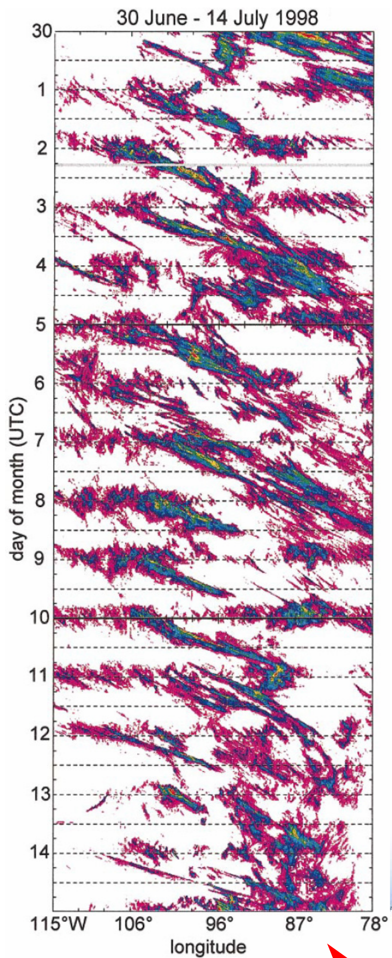
FIG. 4. Total number of NWF outbreaks occurring in 2° Marsden squares for the period 1962–77. Dotted lines indicate major high-frequency axes.



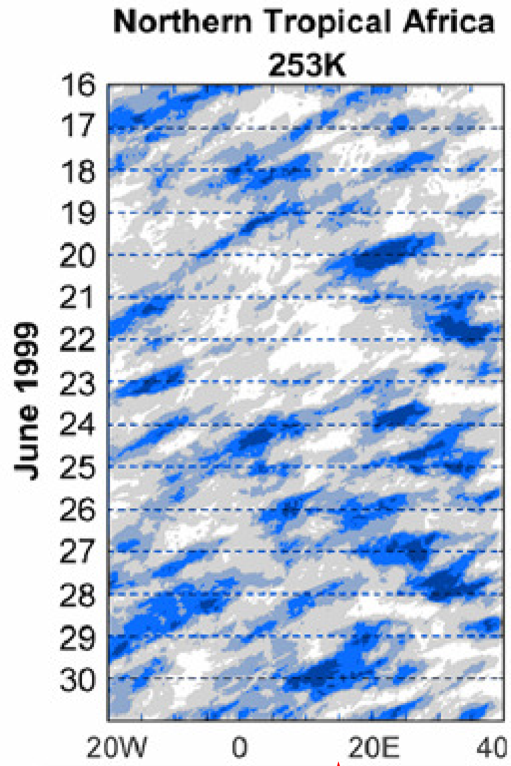


Johns and Hirt (1987)



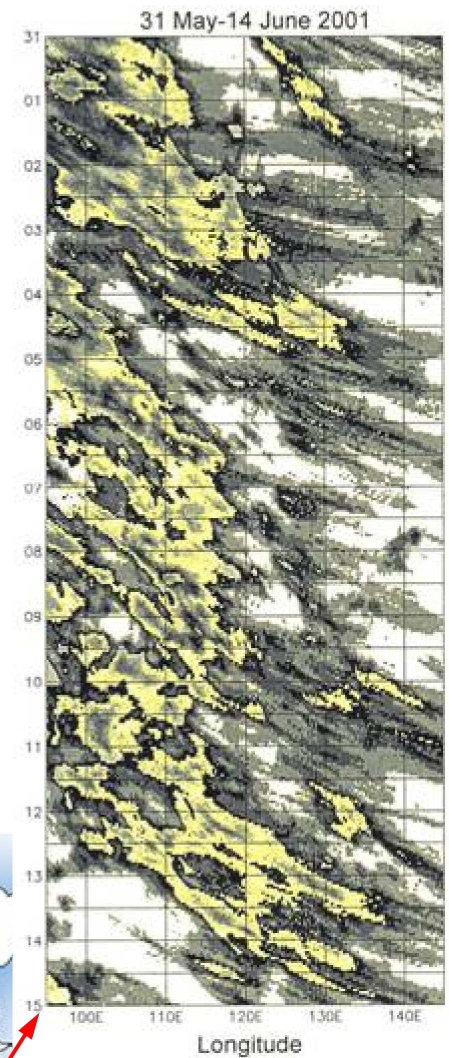


Carbone et al. (2002)

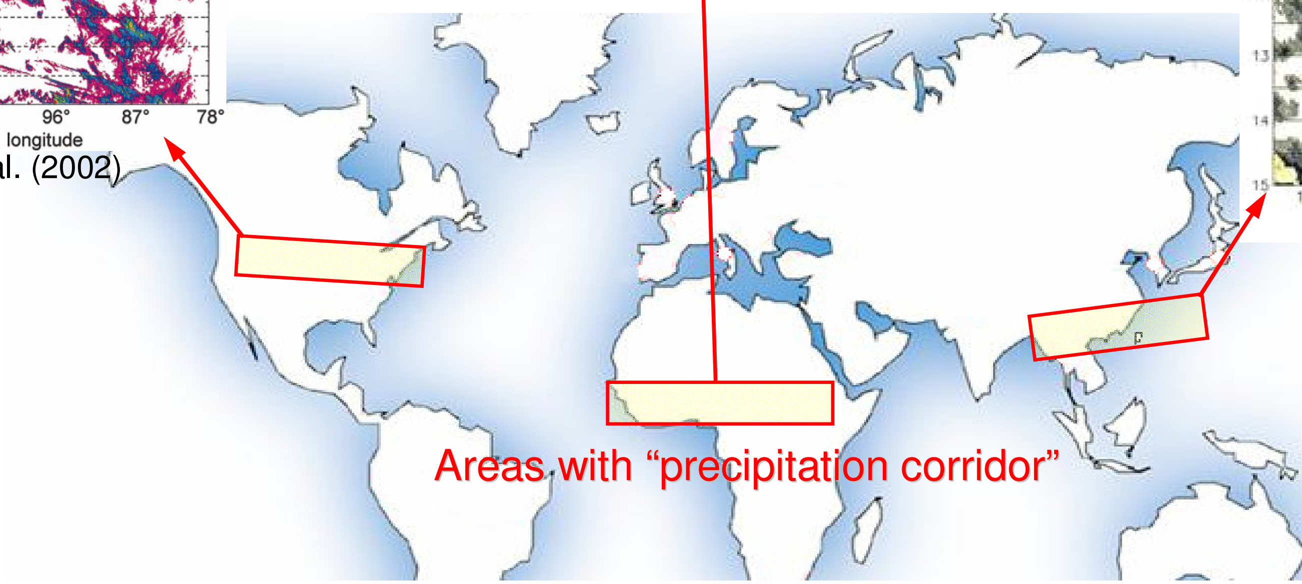


Laing et al. (2008)

Propagating rainfall episodes

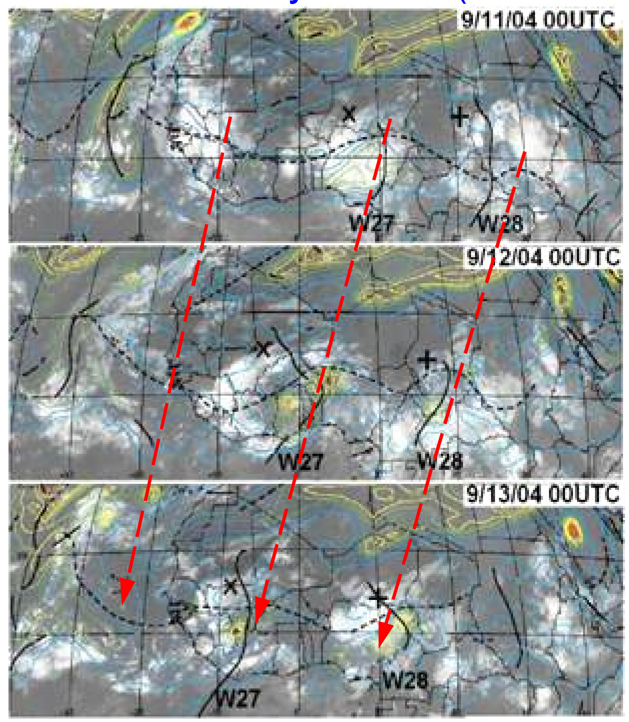


Wang et al. (2004)



Waves?
Perturbations?

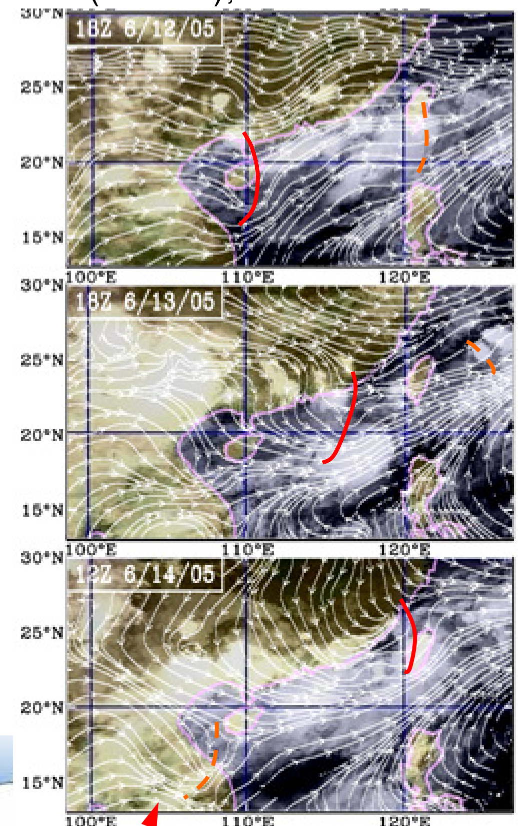
African easterly waves (mid-level)



Berry et al. (2007)

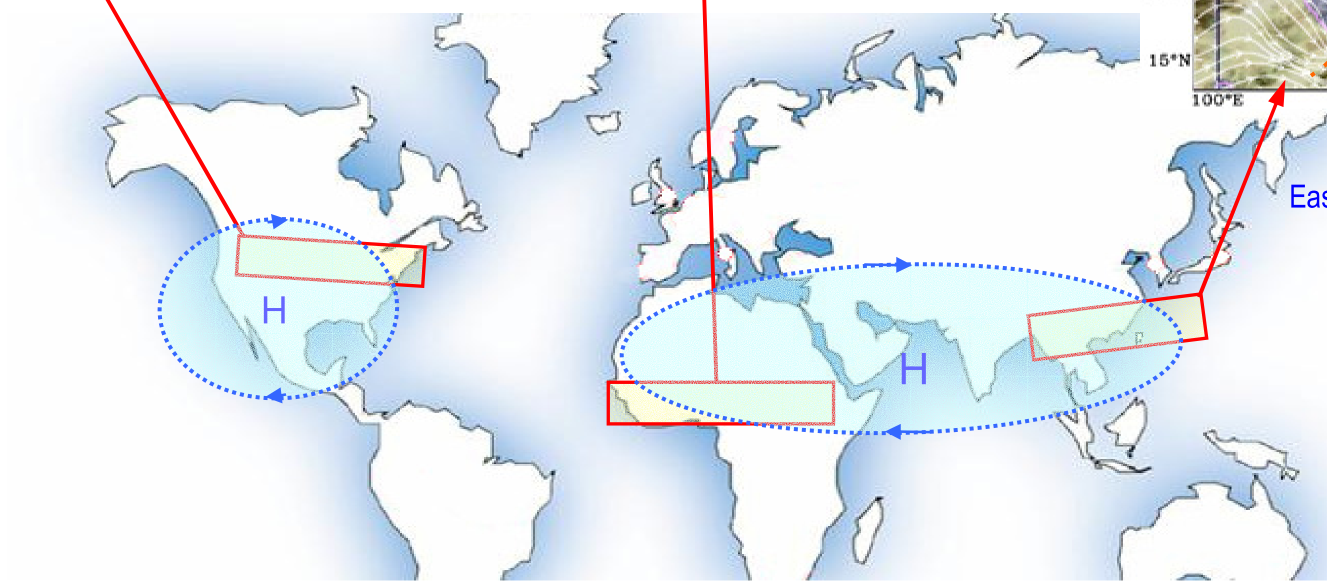
Rainstorm perturbations

$\mathbf{V}$(600mb), IR



Chen et al. (2008)

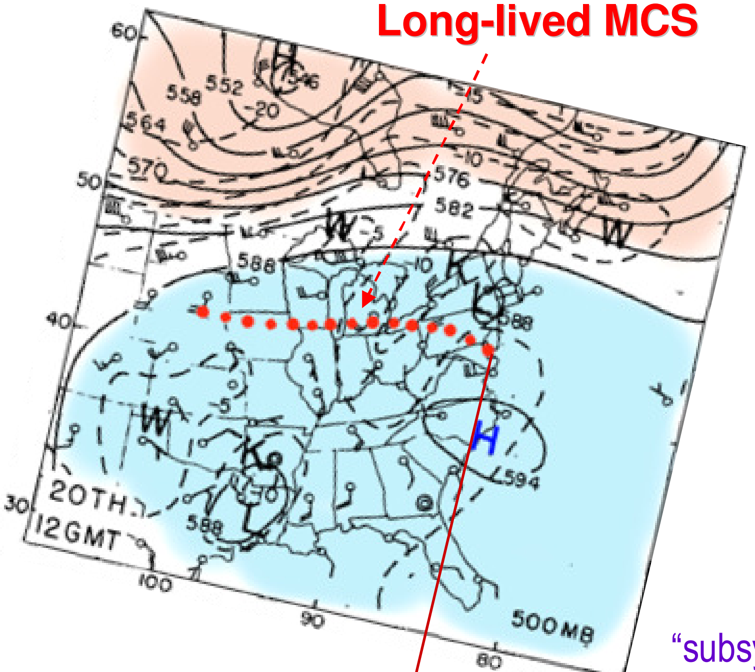
East Asian Monsoon Experiment
(EAMEX; 2008-09)



The Johnstown flood in July 1977

Bosart and Sanders (1981)

Long-lived MCS

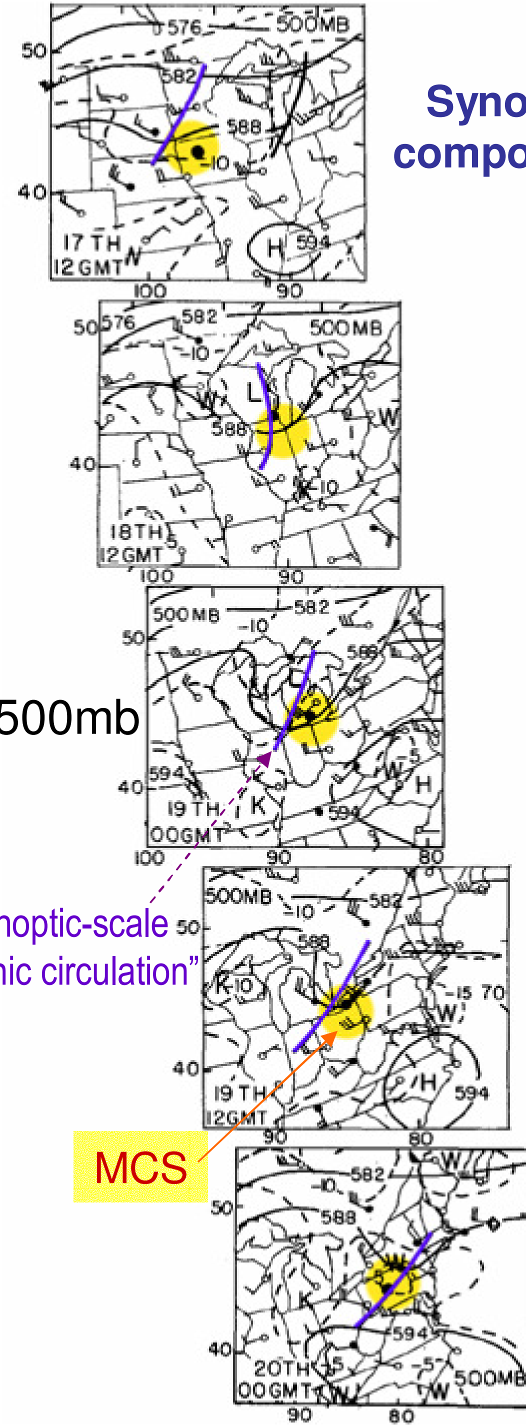


Johnstown, Pennsylvania

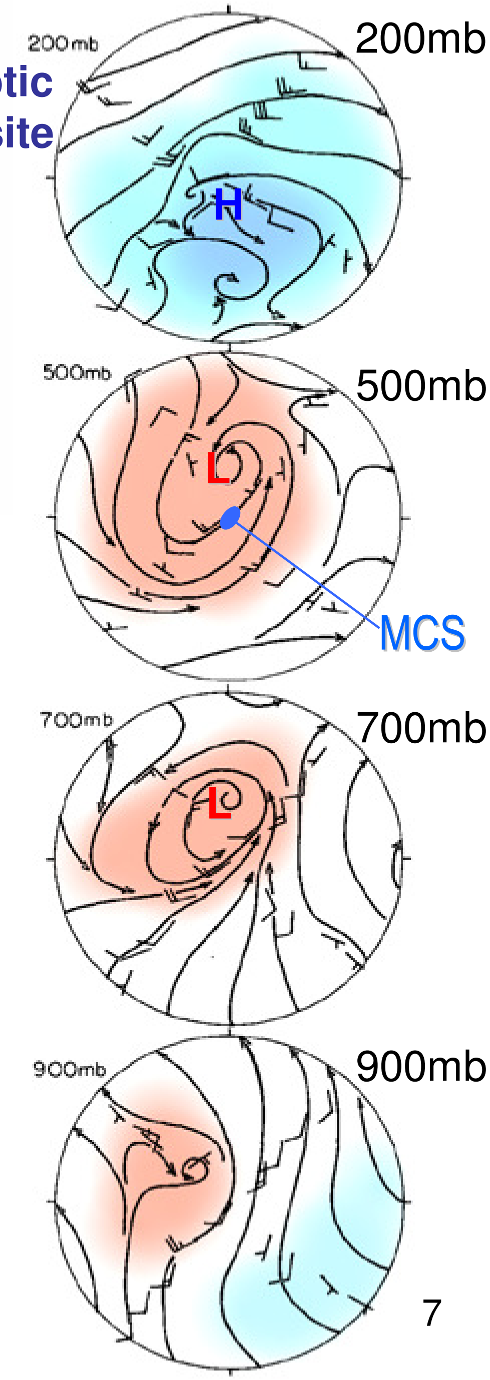
500mb

“subsynoptic-scale cyclonic circulation”

MCS

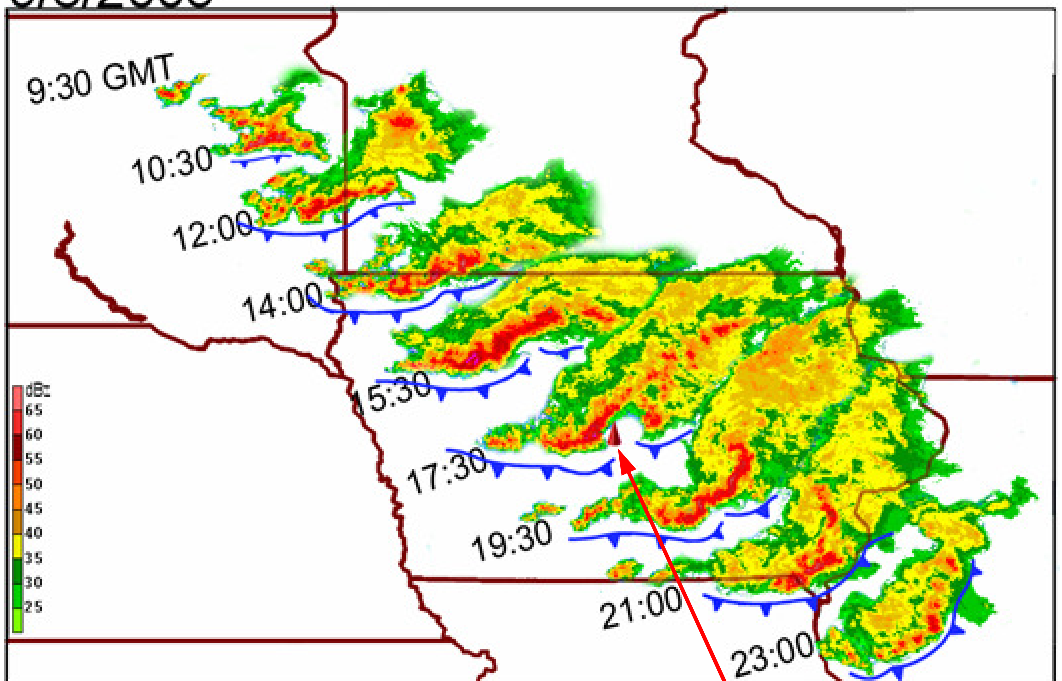


Synoptic composite



A midtropospheric perturbation inducing tornado touchdown at Iowa State Uni.

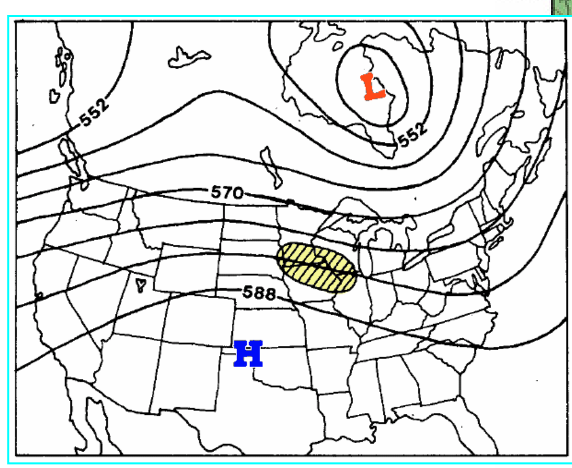
9/8/2005

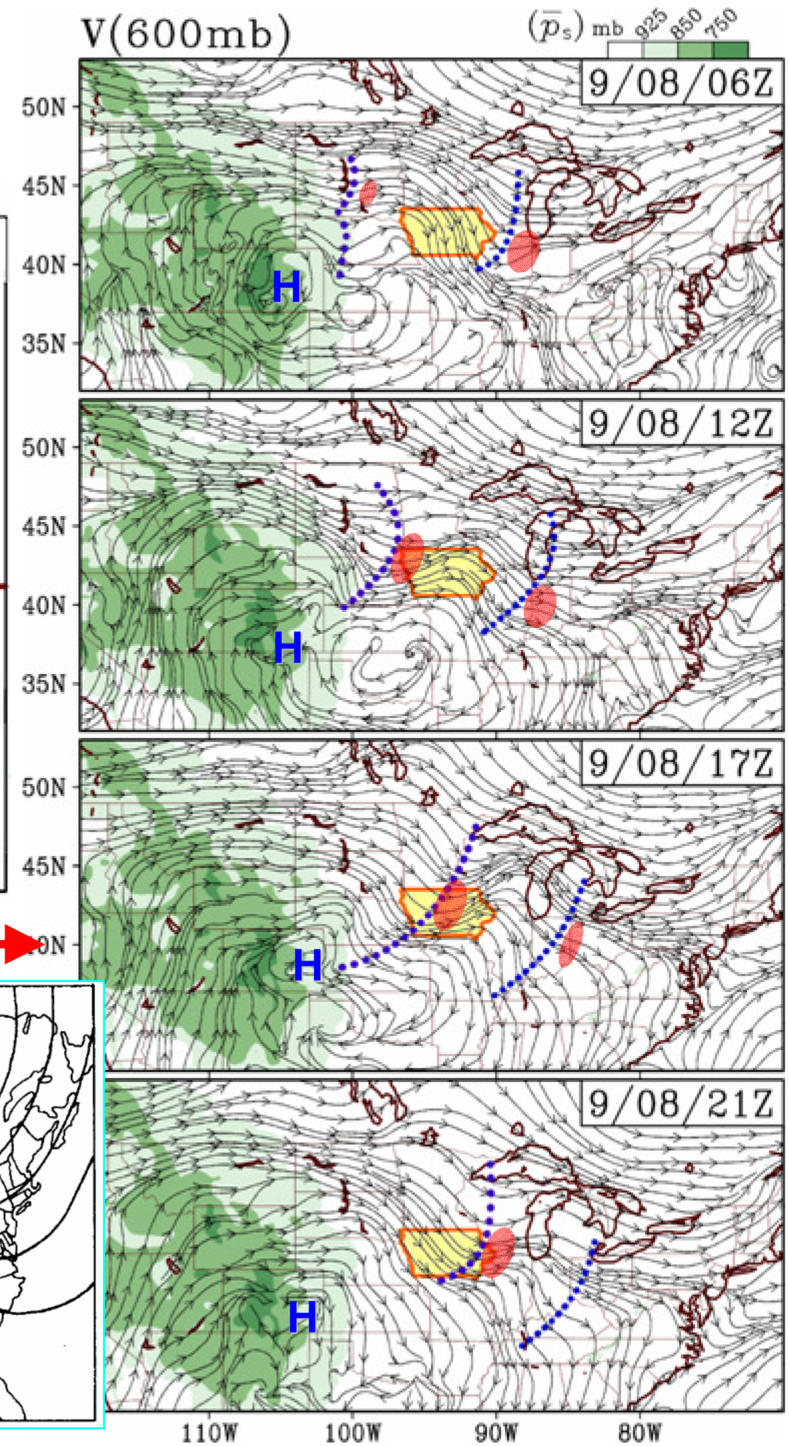


(Chen et al. 2008)

ISU tornado

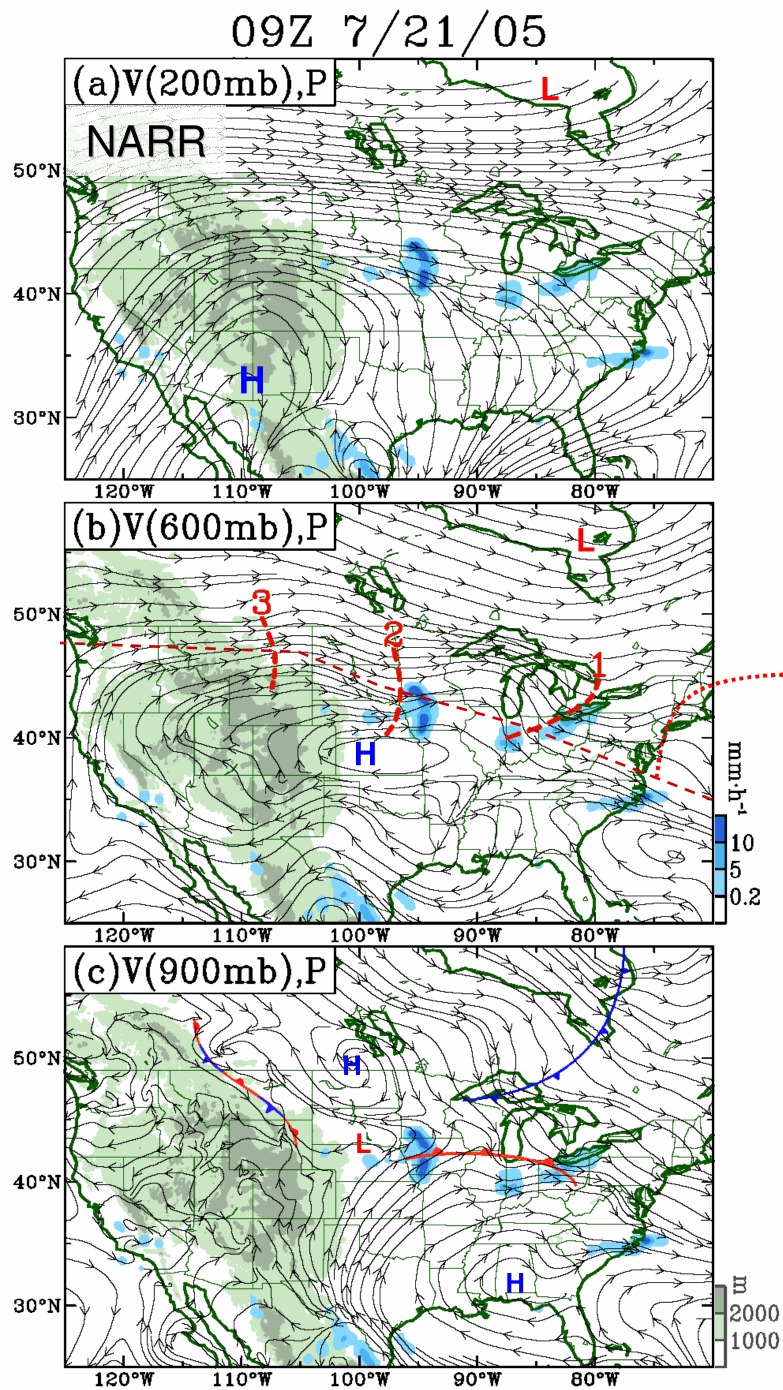
NWF outbreaks

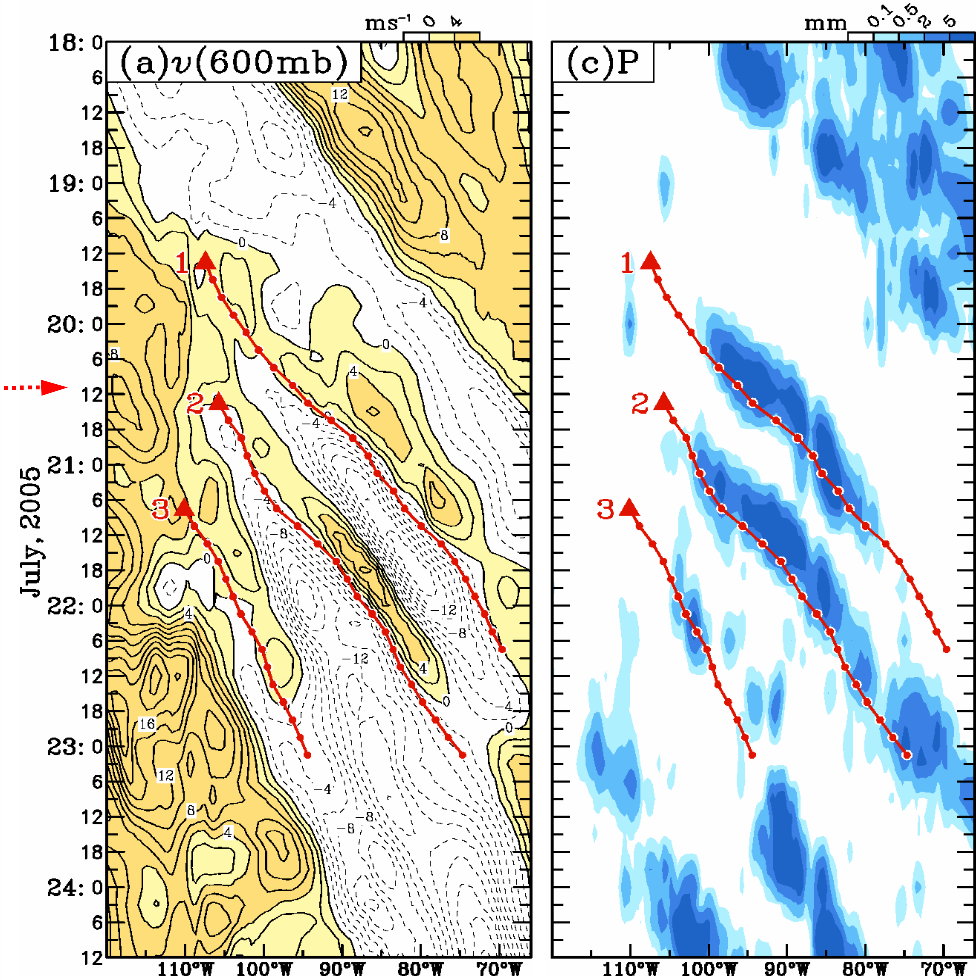




Example case of midtropospheric perturbation (MP)

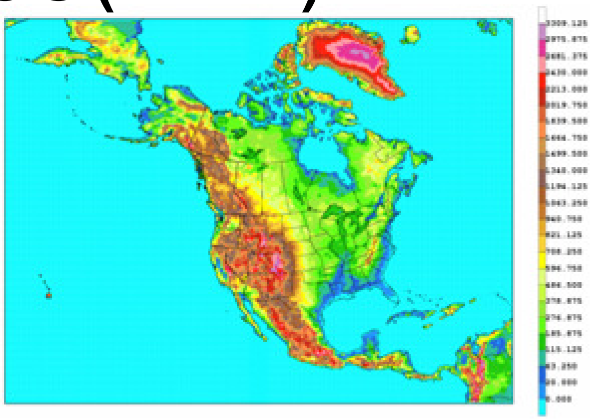
July, 2005





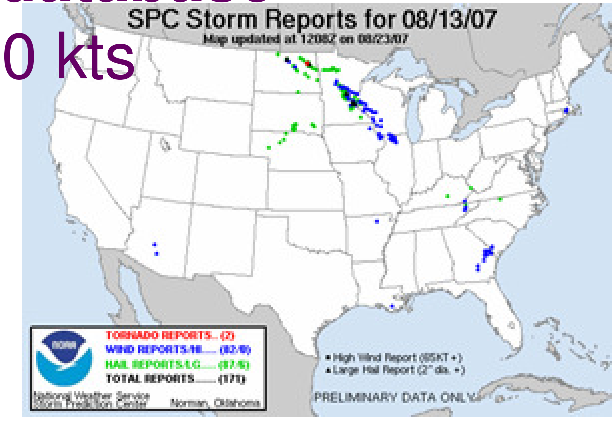
Data:

1. North American Regional Reanalysis (NARR)
32-km / 45-layer / 3-hr resolution
May-Sep, 1997-2006



2. NCEP multi-sensor precipitation
NEXRad + raingauges (Stage II)
4-km/30-min resolution

3. SPC (Storm Prediction Center) **T-storm database**
reports of hail ≥ 0.5” & wind gust ≥ 50 kts
projected onto 2°x2° grid-spacings
→ “convective activity”



4. NAM (North American Mesoscale Model)
July-August, 2005-2006

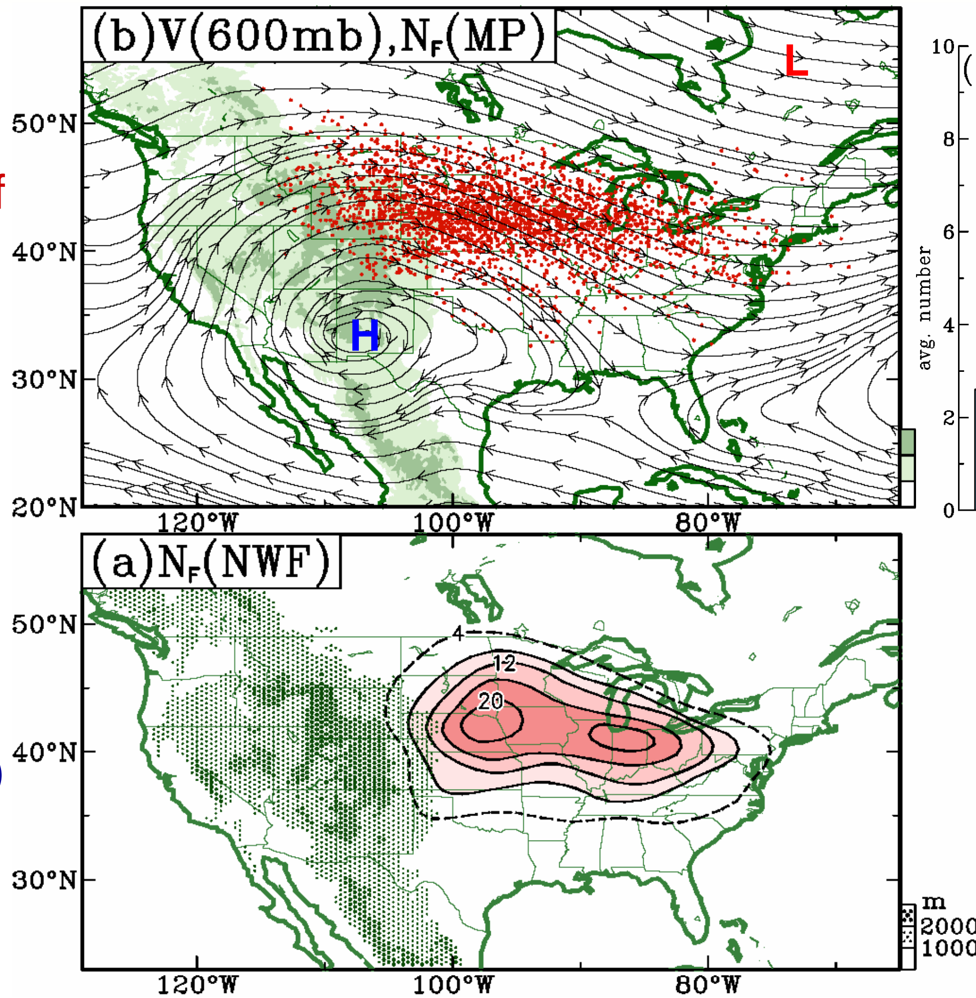
Climatology of "Midtropospheric Perturbations (MPs)"

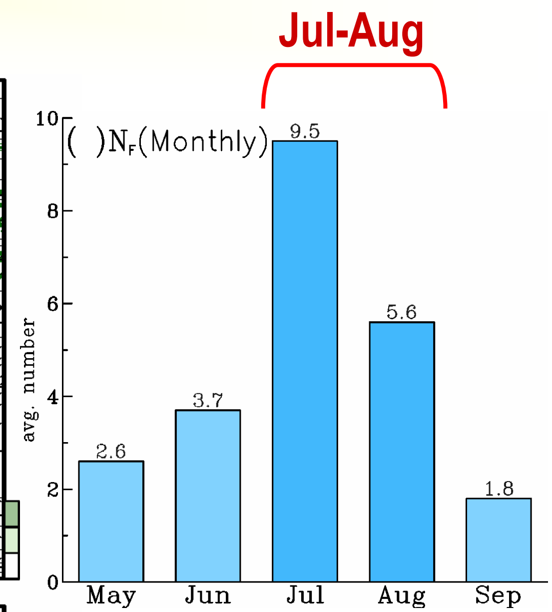
July-August

Areal frequency of MPs (1997-06) *using NARR*

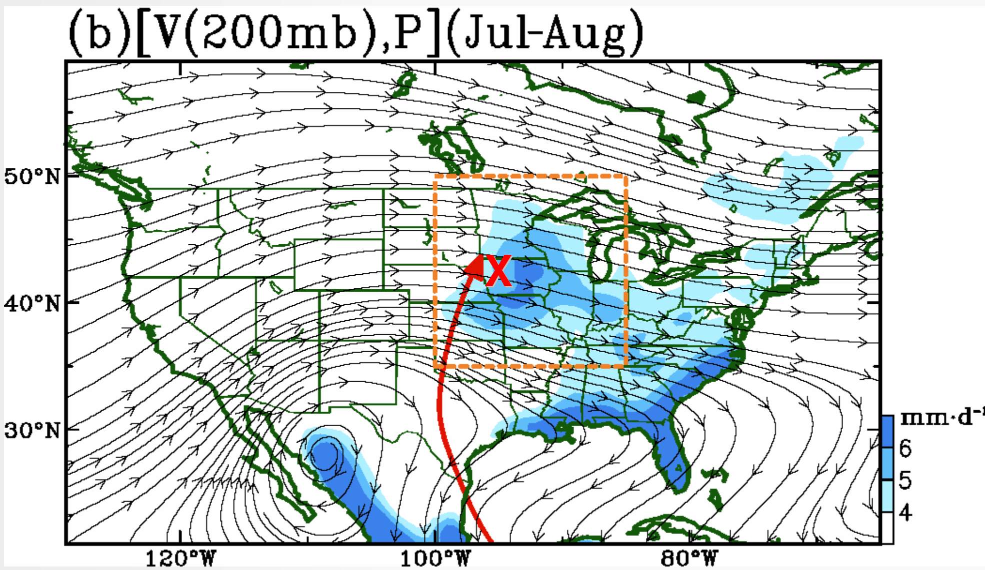
- 3-hr MP position

Areal frequency of NWF outbreaks (1962-77; Johns 1982) *using storm reports*



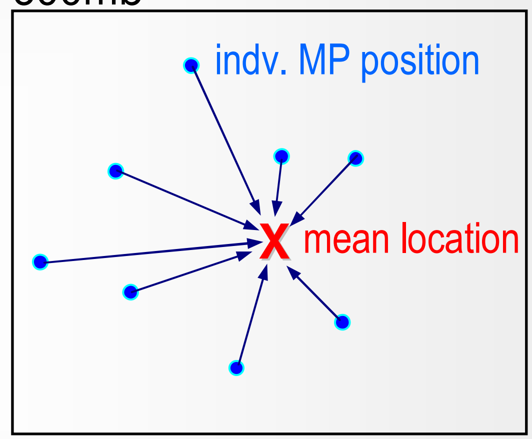


3-D structure of MPs: Composite analysis

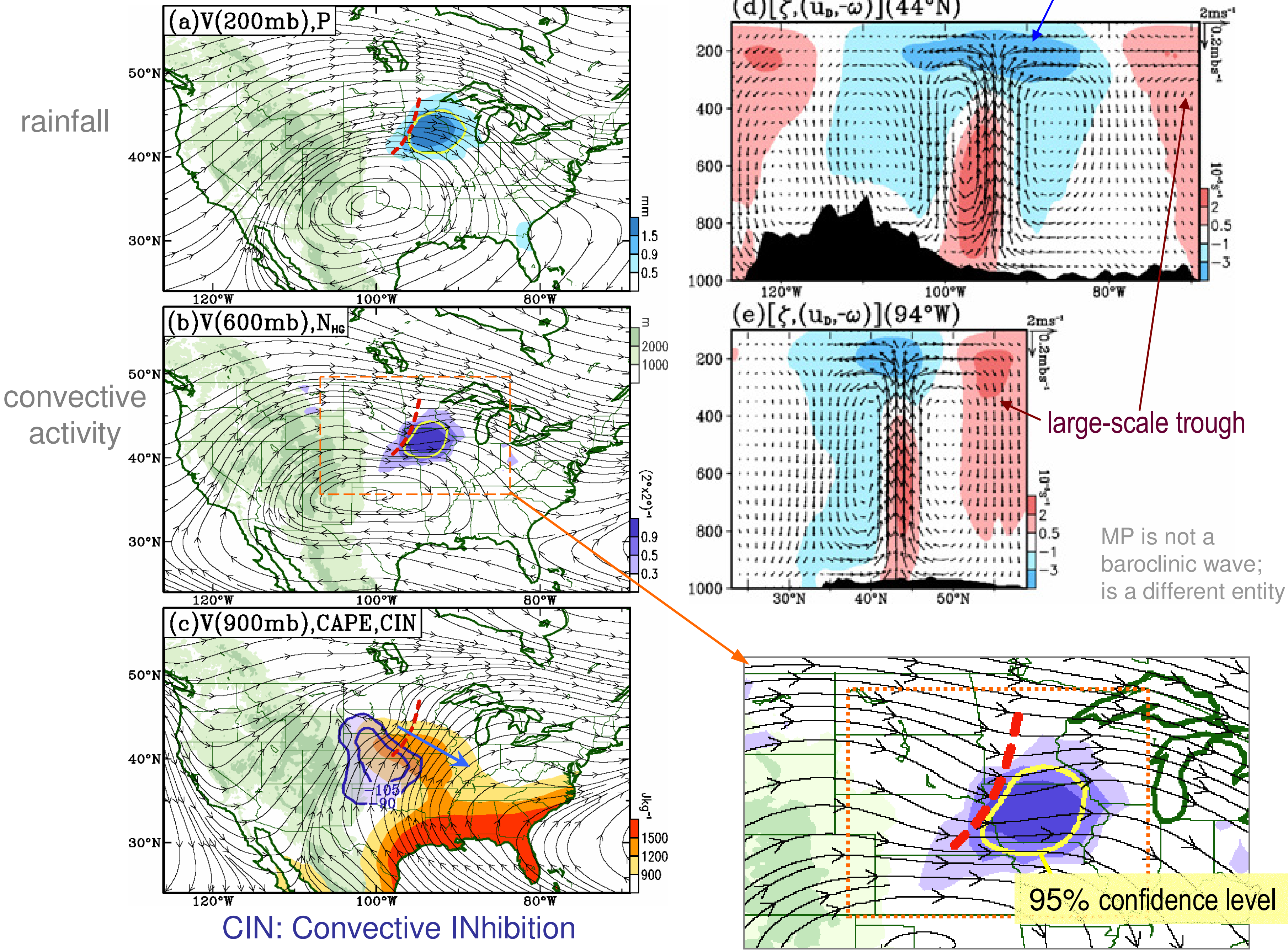


Spatial alignment:

600mb



MP kinetic structure composite

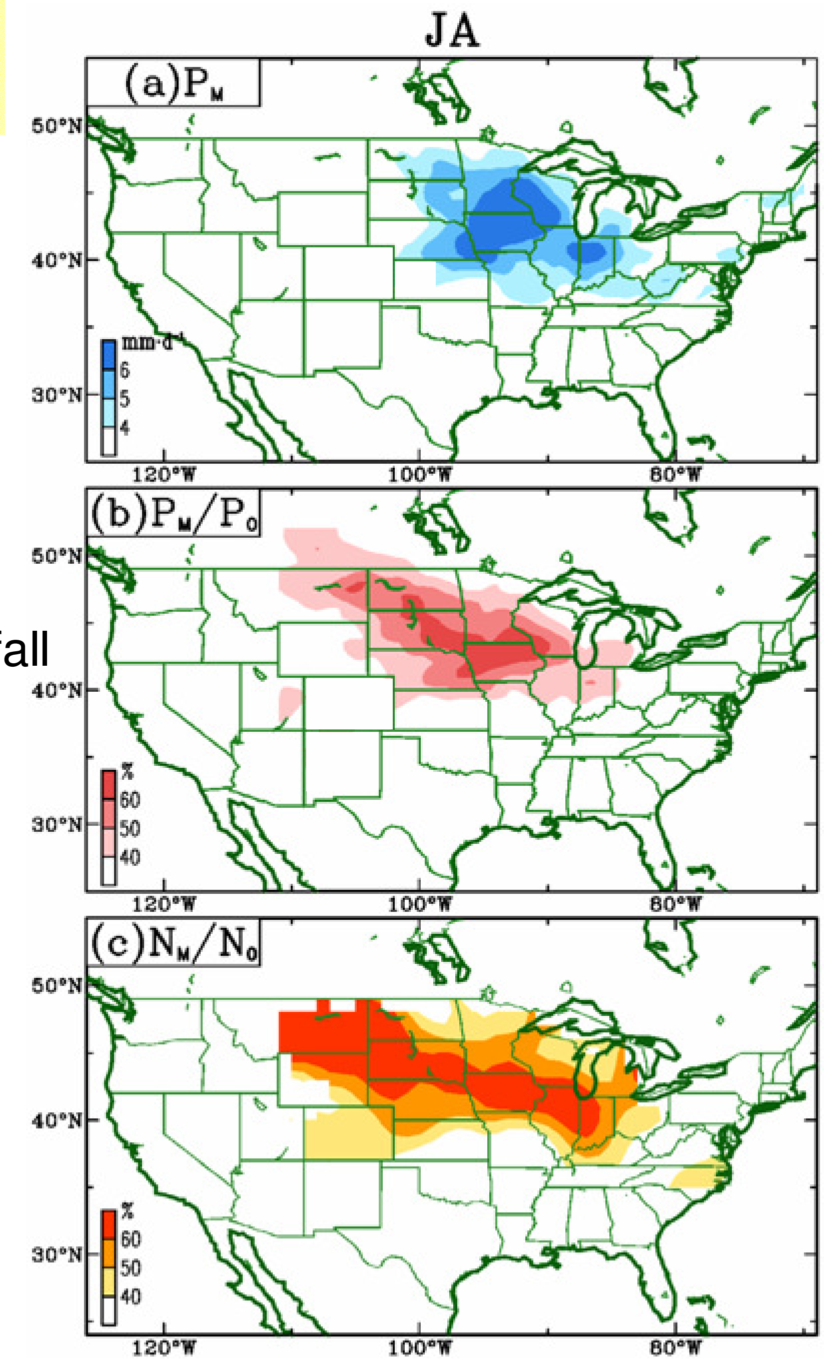


Impact on summer rainfall & conv. activity

MP-related rainfall

Contribution to rainfall

Contribution to convective activity



(accumulated P over a 15°x10° domain following each MP)

Hail and gusty wind reports from SPC

Forecast: perturbations vs. rainfall forecasts

Known Deficiencies:

Operational forecasts of MCS rainfall in a weakly forced environment are poor.

(Olson et al. 1995; Jankov and Gallus 2004; Liu et al. 2006)

Operational forecasts of summer propagating rainfall are (also) poor.

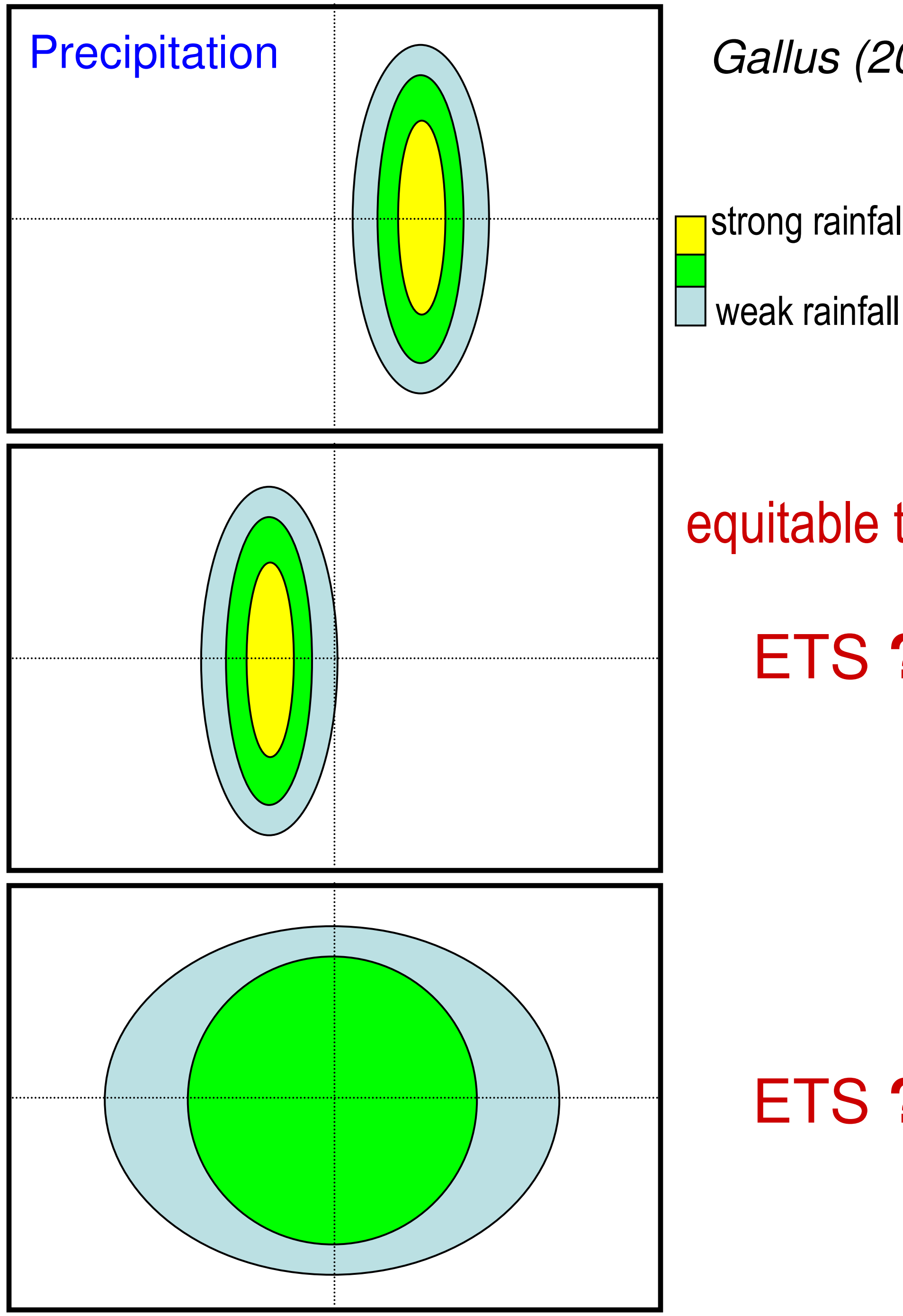
(Davis et al. 2003; Clark et al. 2007)

Gallus (2007)

Observation

Forecast 1

Forecast 2



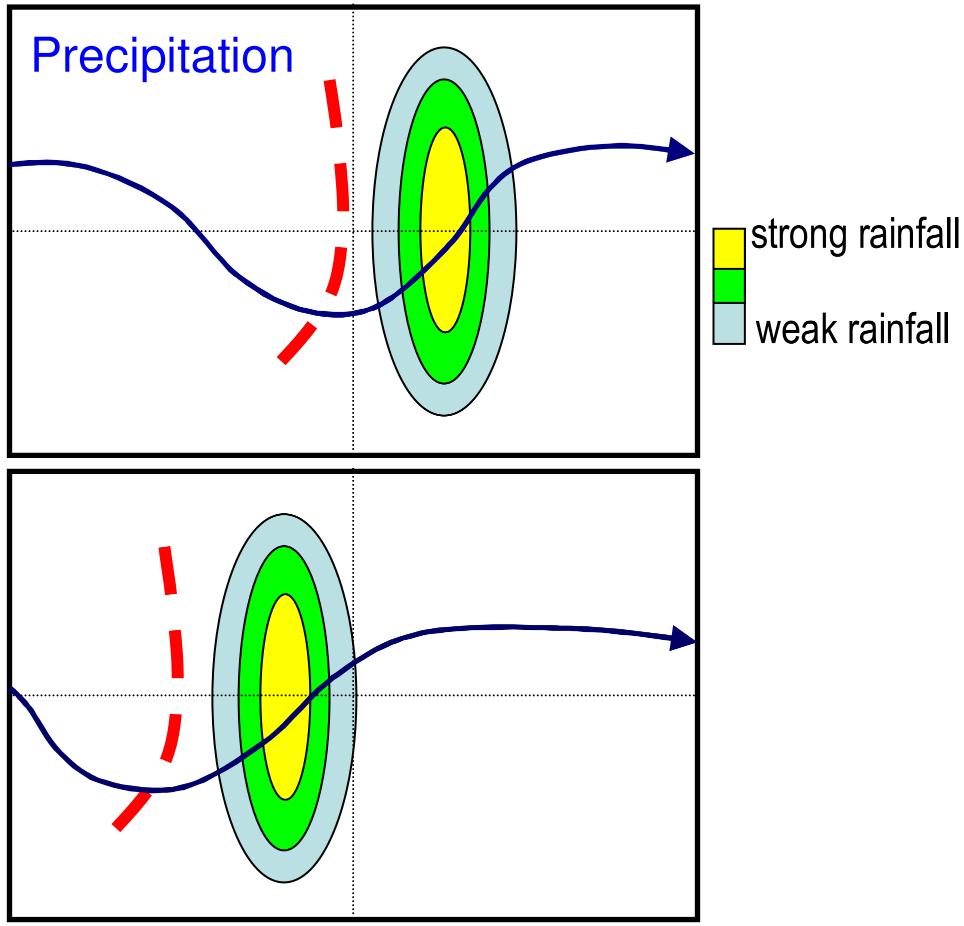
equitable threat score

ETS **?**

ETS **?**

Observation

Forecast

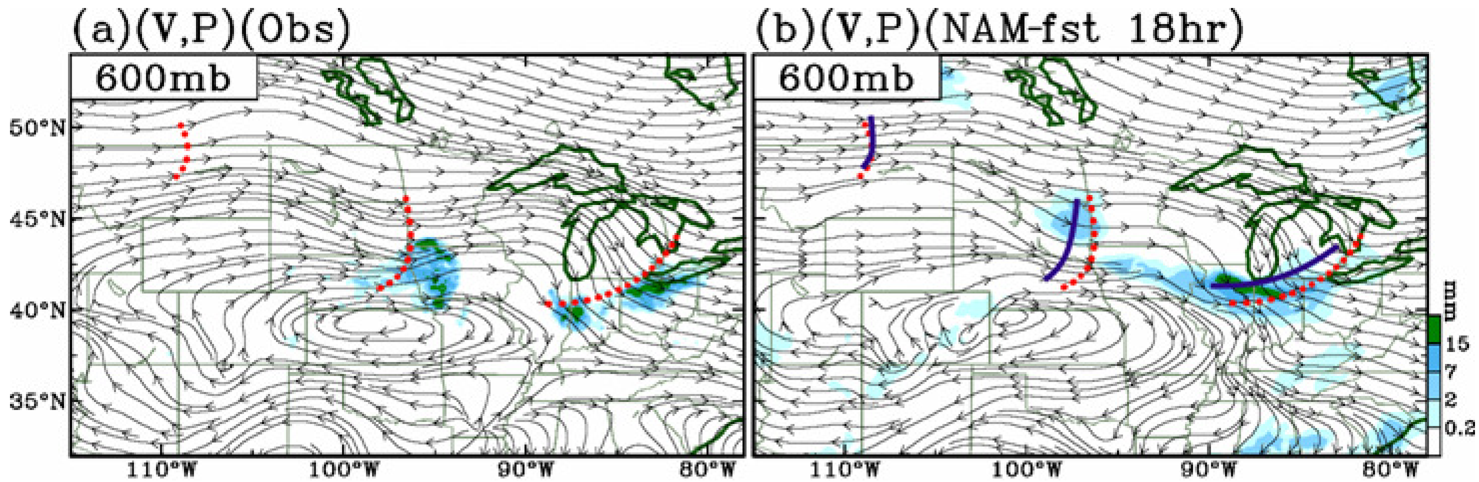


Position error of perturbations?

Snapshots of the NAM performance

09Z 7/21/05

Case 1

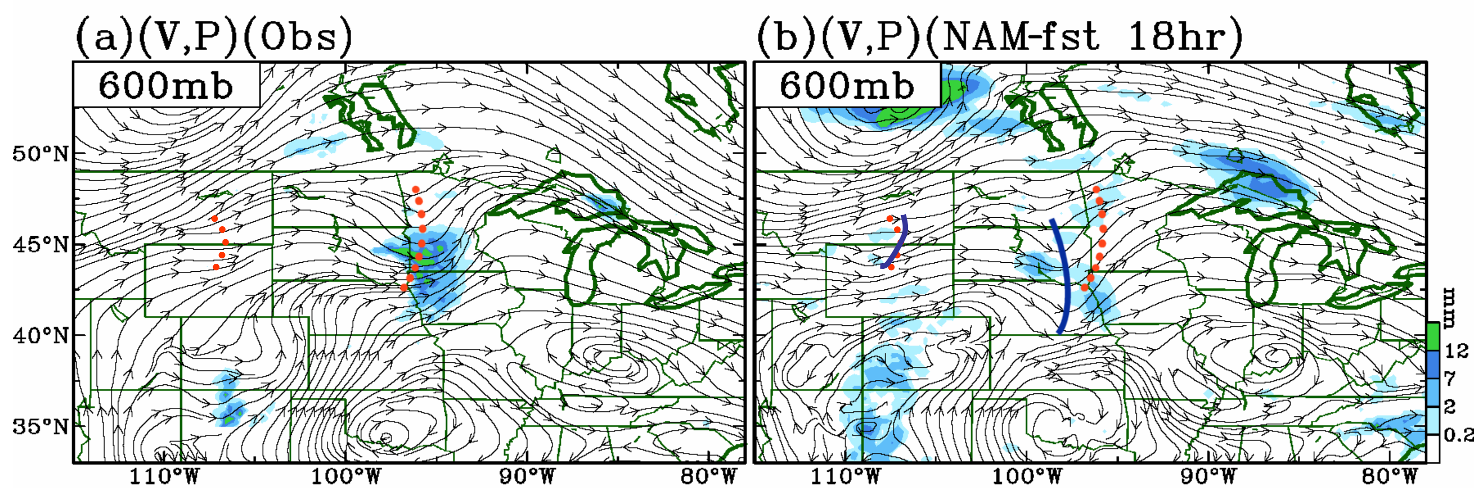


Observation

Forecast

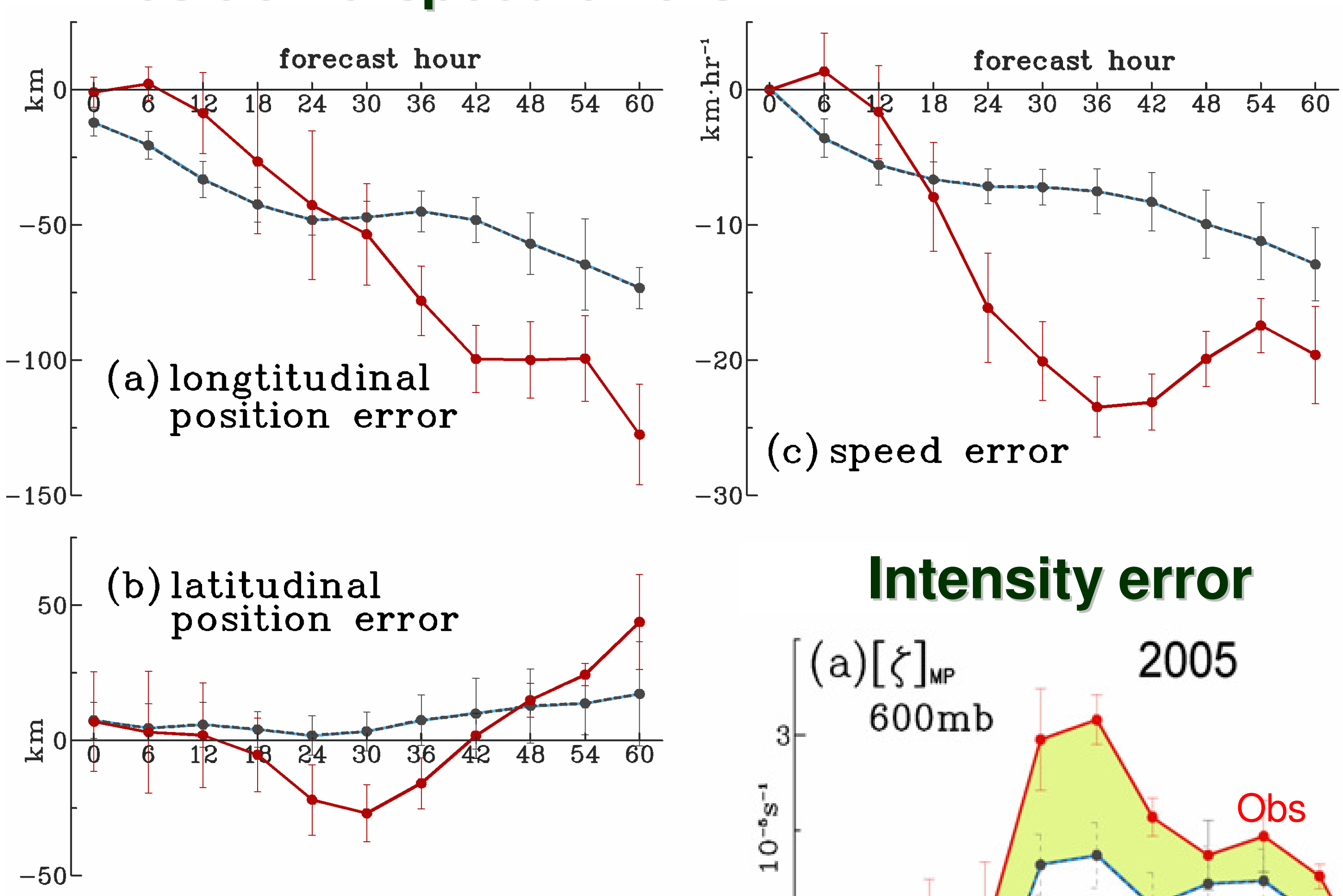
09Z 8/5/06

Case 2



- Propagation too slow
- Precipitation too small

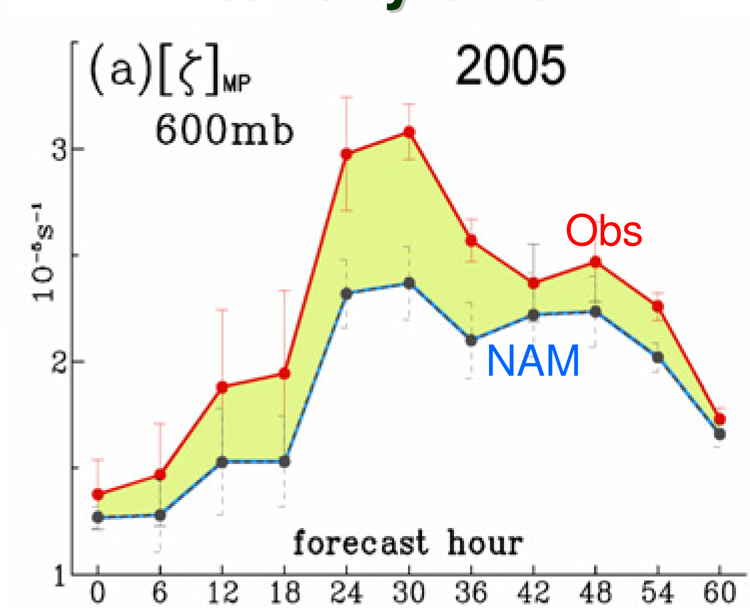
Position & speed errors



2005 NAM: Eta
2006 NAM: WRF

Totally 25 MP cases
(Jul-Aug, 2005-06)

Intensity error



$$\zeta_t \approx -\mathbf{V} \cdot \nabla \zeta$$

$$c_\zeta \equiv \frac{\Delta L \cdot \zeta_t}{\zeta}$$

Estimated propagation speed
(Carr & Elsberry 1995)

$$c_\zeta(NAM)$$

Reconstructed speed

$$c_\zeta^*$$

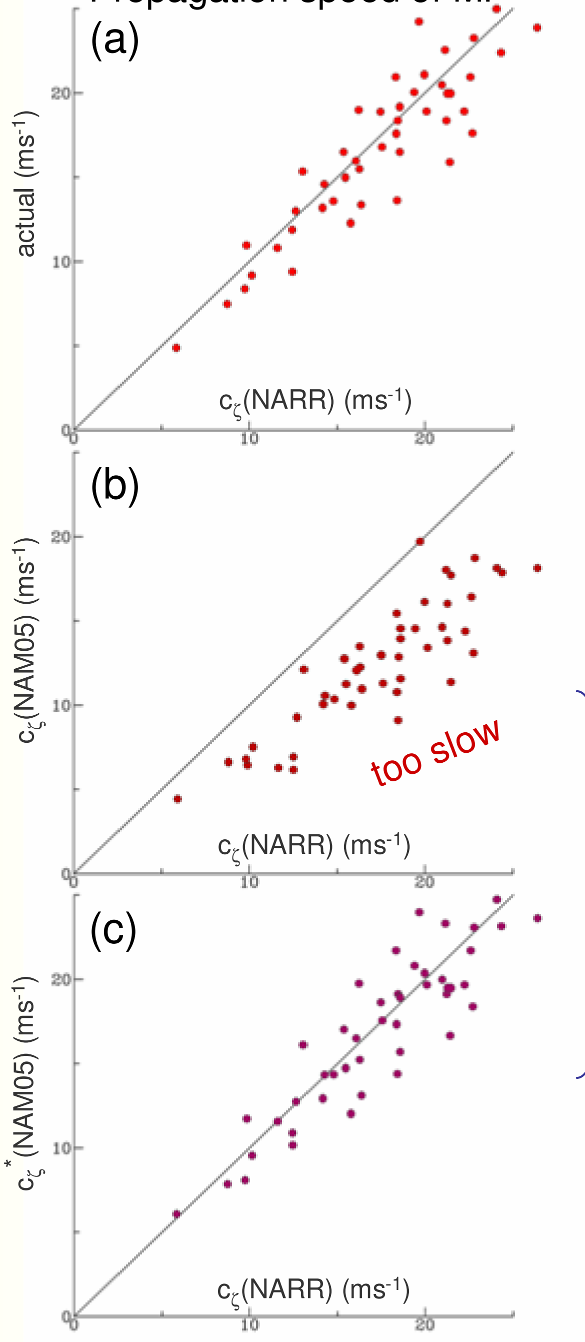
$$\zeta_t^* \approx -\mathbf{V}^* \cdot \nabla \zeta^*$$

perturbation ambient flow

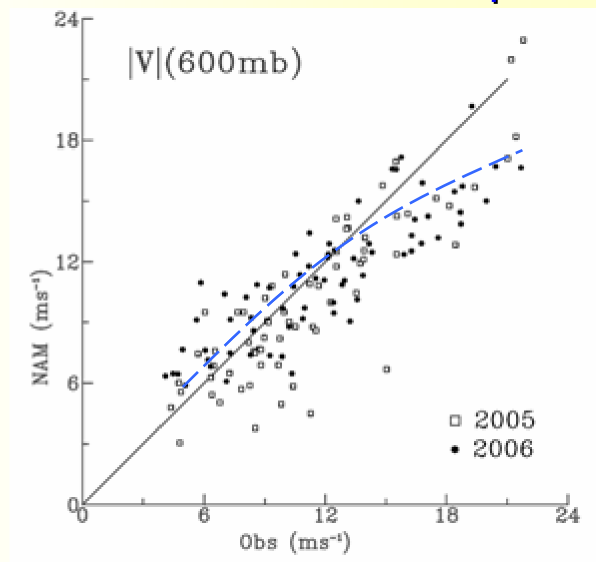
$$V^* = V_{NARR}^S + V_{NAM}^L$$

$$\zeta^* = \zeta_{NARR}^S + \zeta_{NAM}^L$$

Propagation speed of MP



Environmental wind speed



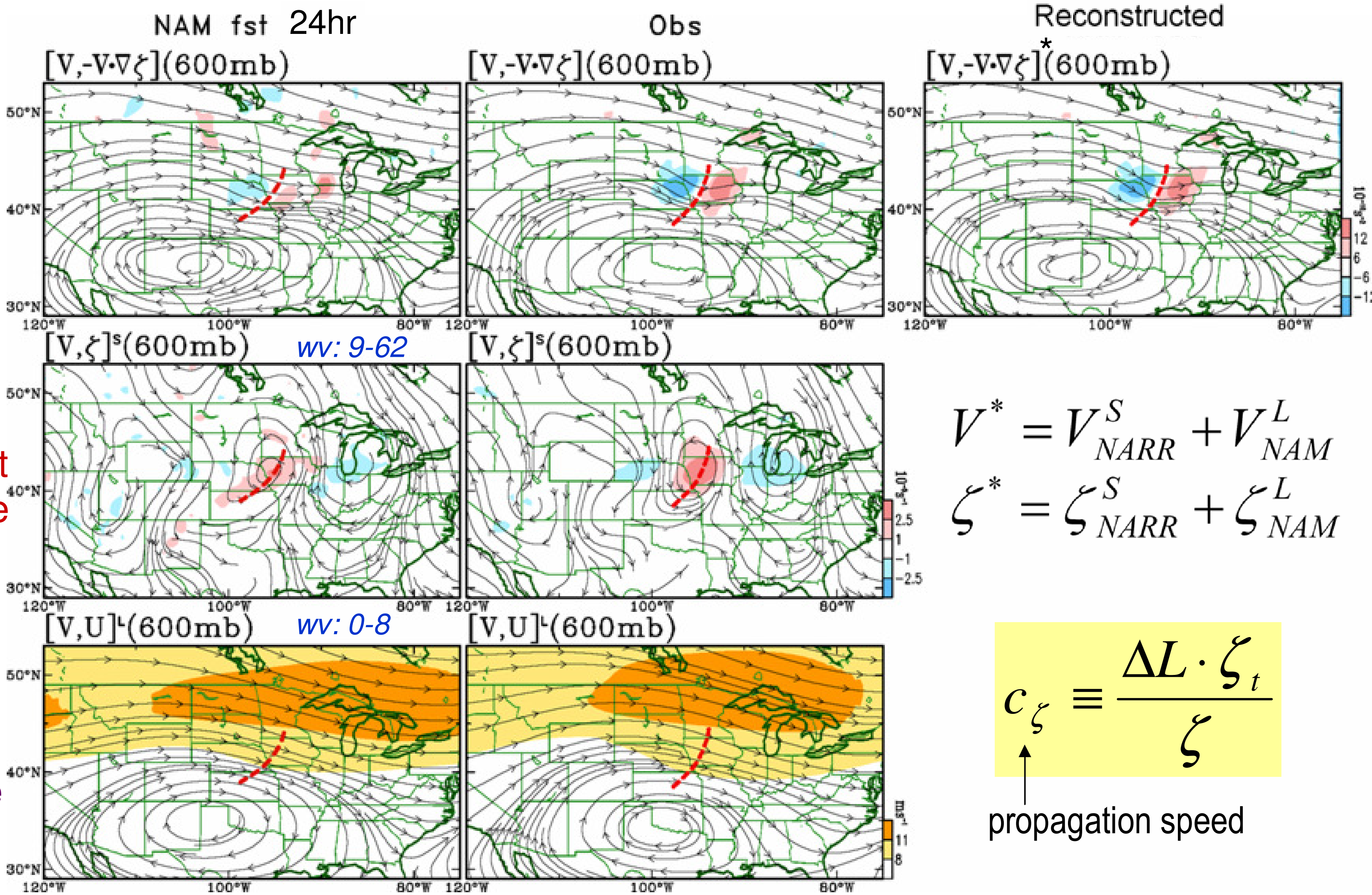
Undersimulated ζ leads to underpredicted MP propagating speed

MP composite: *applying Fourier scale separation*

total

short wave

long wave



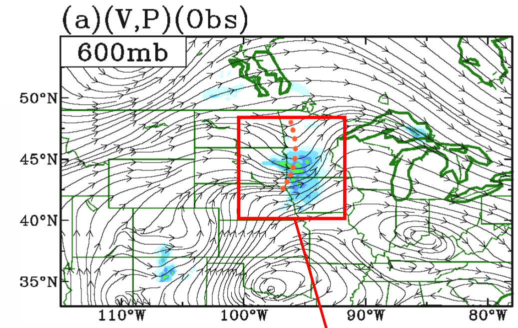
$$V^* = V^S_{NARR} + V^L_{NAM}$$

$$\zeta^* = \zeta^S_{NARR} + \zeta^L_{NAM}$$

$$c_\zeta \equiv \frac{\Delta L \cdot \zeta_t}{\zeta}$$

propagation speed

Precipitation forecasts



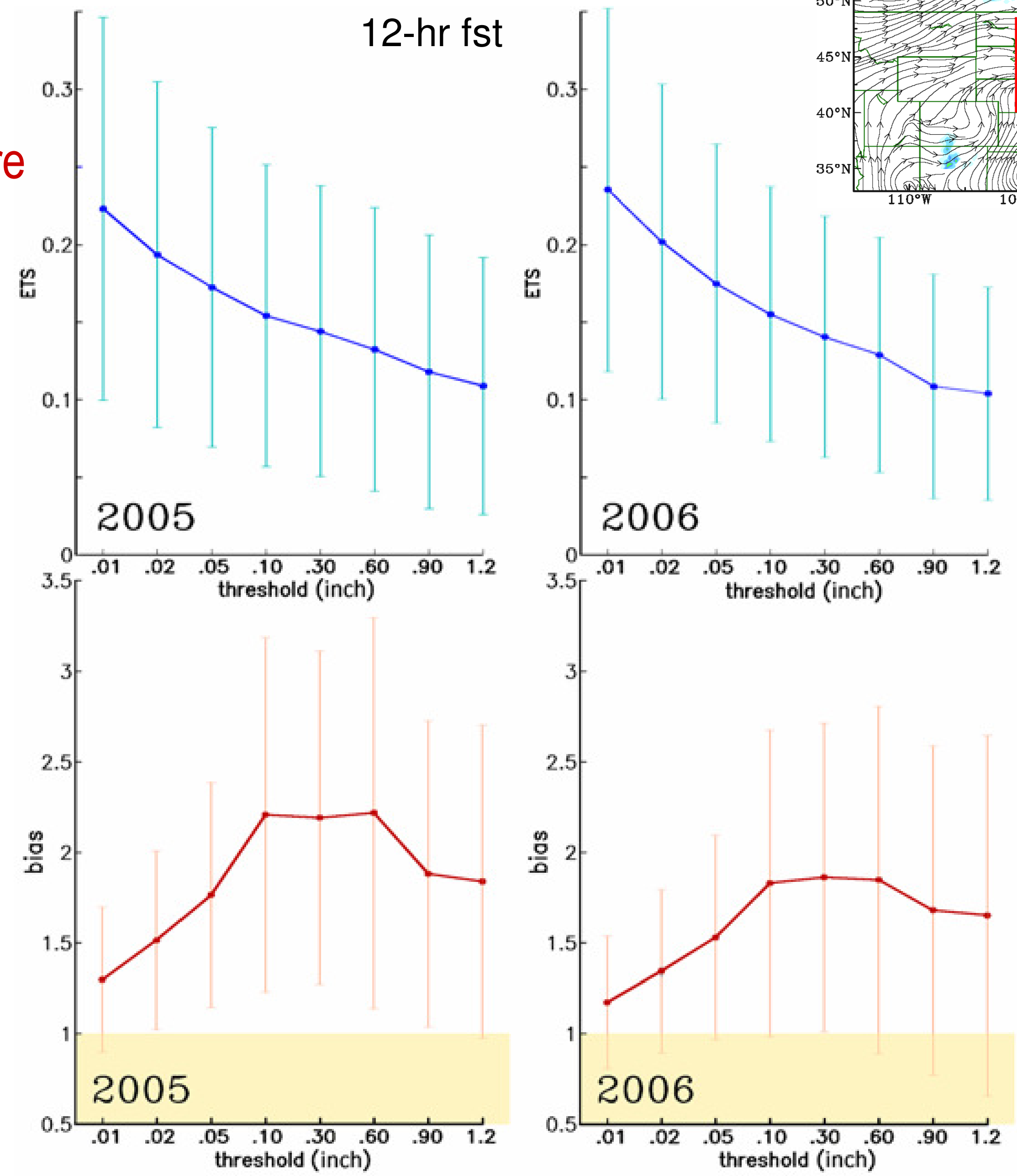
ETS domain following each MP: a mobile approach

12-hr fst

equitable threat score

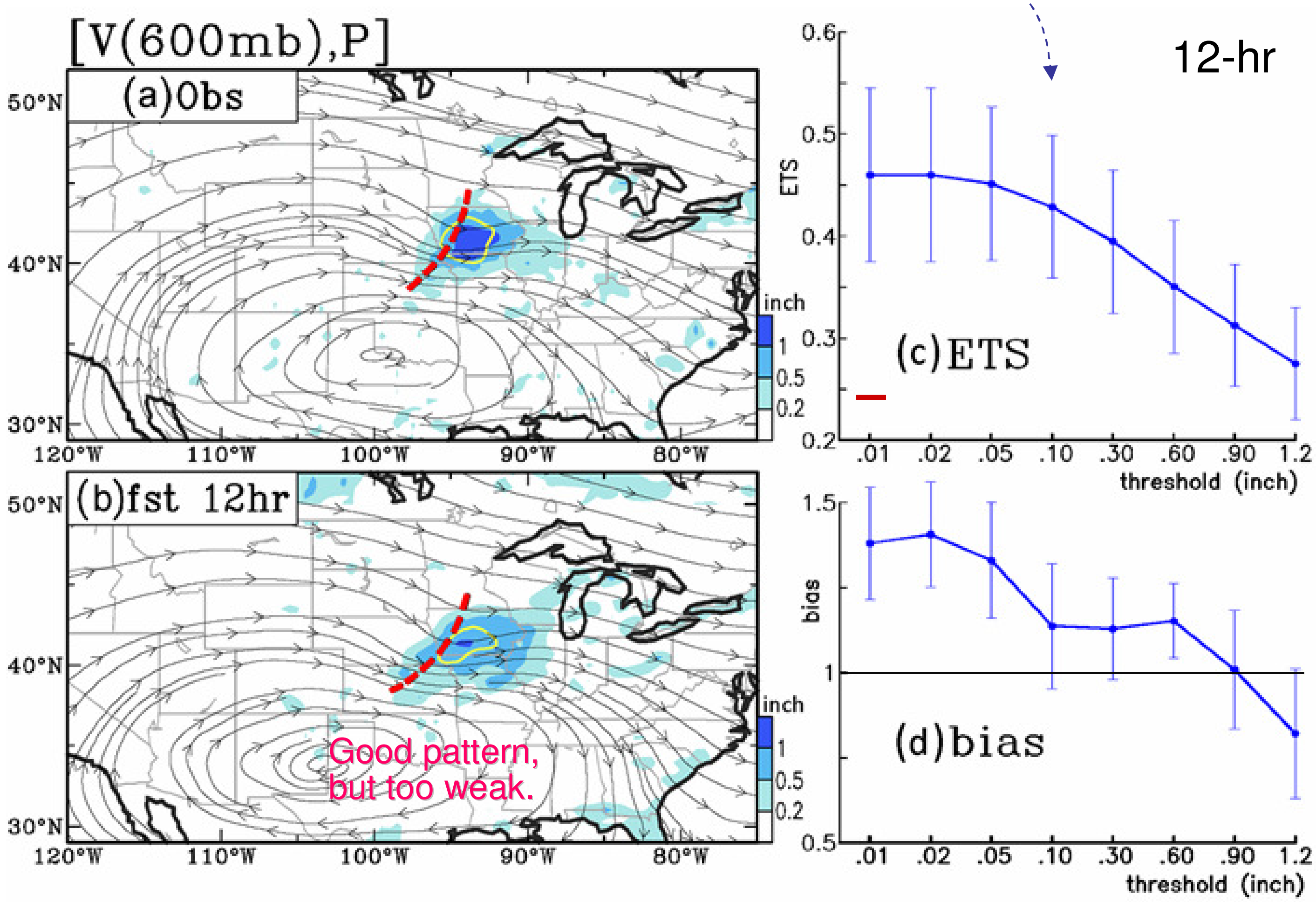
Mobile ETSs

Mobile biases



Forecast scores **after** aligning forecasted MPs with observed MPs

(Composite)



Position errors of MPs contribute to low ETSs of rainfall forecast.

Precipitation process of MPs

Modified ***water vapor budget*** equation (Chen 1985)

$$\frac{\partial \mathrm{W}}{\partial \mathrm{t}} + \nabla \cdot \vec{\mathrm{Q}} = \mathrm{E} - \mathrm{P} \qquad , \mathbf{Q} = \int_{p_S}^{0} (\mathbf{V} \cdot q)\, dp$$

$$\vec{\mathrm{Q}} = \vec{\mathrm{Q}}_{\mathrm{R}} + \vec{\mathrm{Q}}_{\mathrm{D}} = \mathrm{k} \times \nabla \psi_{Q} + \nabla \chi_{Q}$$

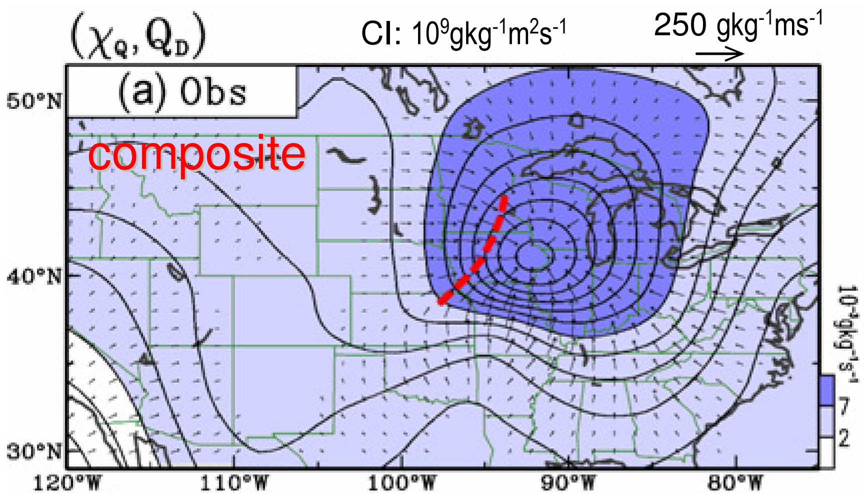
rotational divergent

$$\frac{\partial \mathrm{W}}{\partial \mathrm{t}} + \boxed{\nabla^{2} \chi_{Q}} = \mathrm{E} - \mathrm{P}$$

$$\boxed{\chi_{Q}} = \nabla^{-2} (\nabla \cdot \vec{\mathrm{Q}}_{\mathrm{D}}) \approx \boxed{\nabla^{-2} (-\mathrm{P})}$$

Potential function of water vapor convergence

$$\chi_Q = \nabla^{-2}(\nabla \cdot \vec{Q}_D)$$

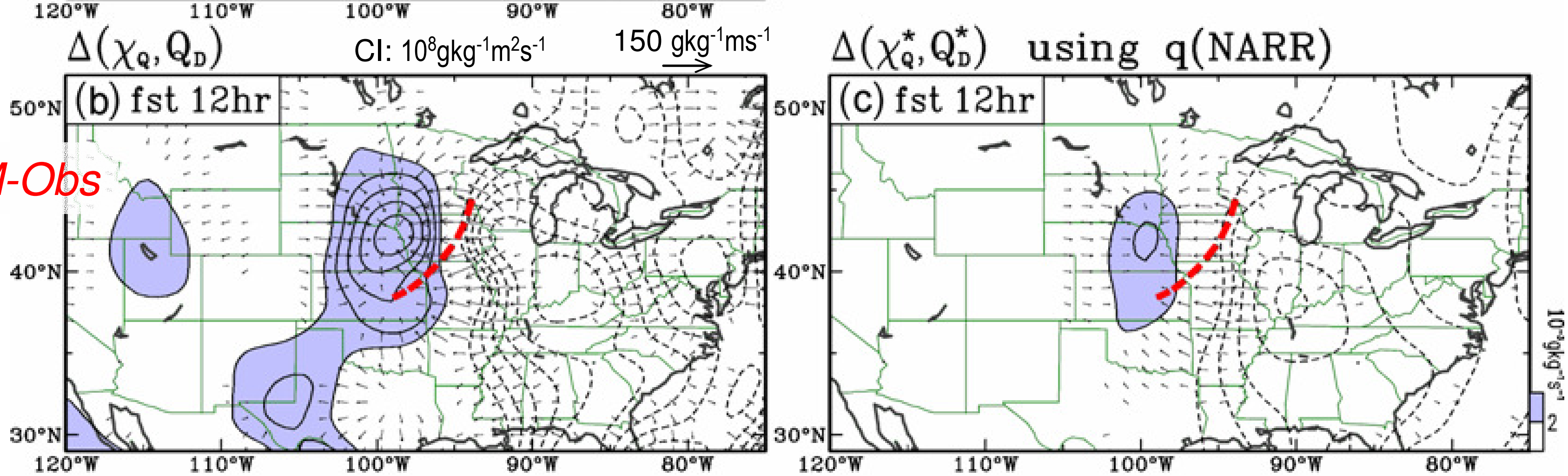


specific humidity

$$\mathbf{Q}^* = \int_{p_S}^{0} (\mathbf{V}_{\mathrm{NAM}} \cdot q_{\mathrm{NARR}})\, dp$$

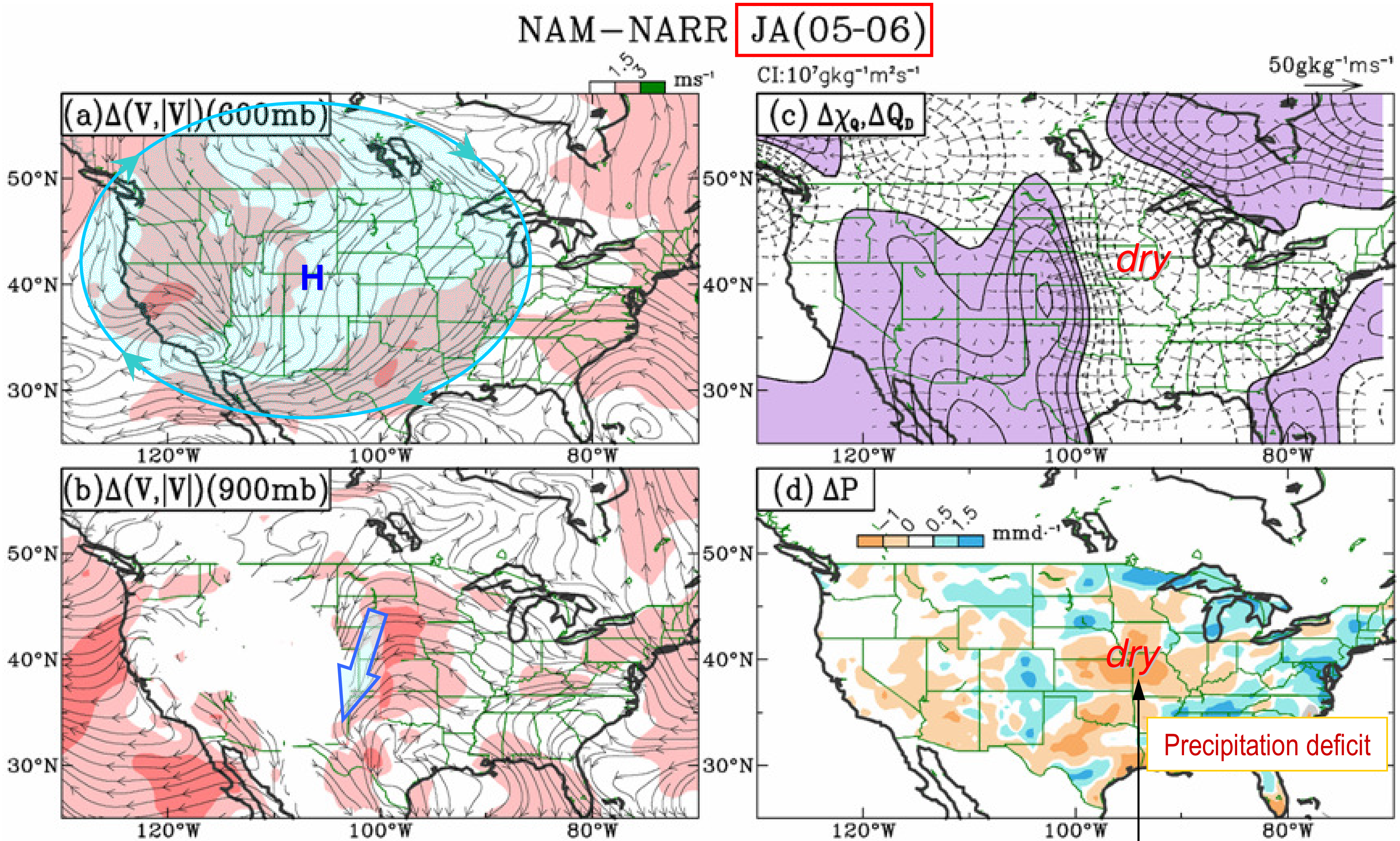
$$\chi_Q^* = \nabla^{-2}(\nabla \cdot \vec{Q}_D^*)$$

NAM-Obs



NAM is “too dry” in terms of atmos moisture

System bias of NAM: bias in model climatology



1) Monsoon anticyclone is oversimulated
2) LLJ strength is undersimulated
3) Water vapor convergence is too weak

Part-1 conclusions:

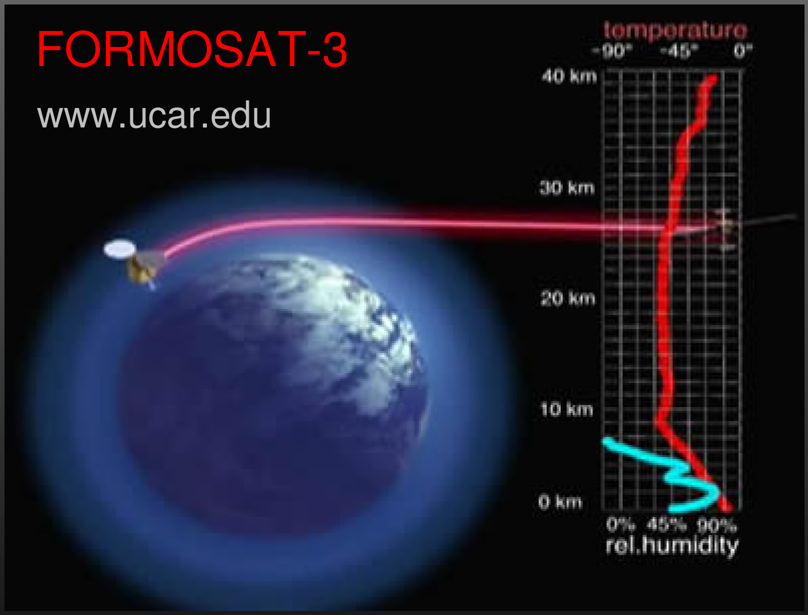
- MPs provide forcing mechanisms for T-storms under weakly forced environments.
- MPs regulate the propagation of mid-summer MCSs
- Correcting the magnitude of forecasted MPs should improve forecasts of propagating convective rainfall.

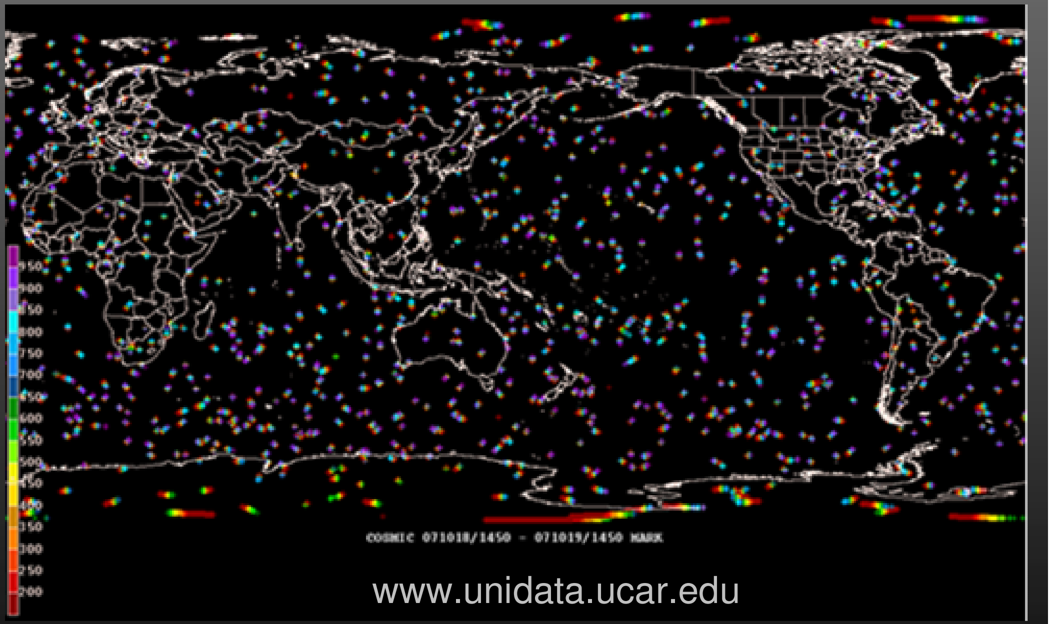
Postscript: None of the CPSs worked to improve it (based on WRF).
WRF 4-km run mode (cloud resolving) improved the propagation.

Future work: Assessing how GPS-QSCAT combined assimilations can improve mesoscale forecast models on MPs

2) Impact of FORMOSAT-3/COSMIC Observations on Global Forecast System (GFS) Predictions in the Northern Hemisphere

CWB GFS (Taiwan), *not* NCEP GFS, sorry!





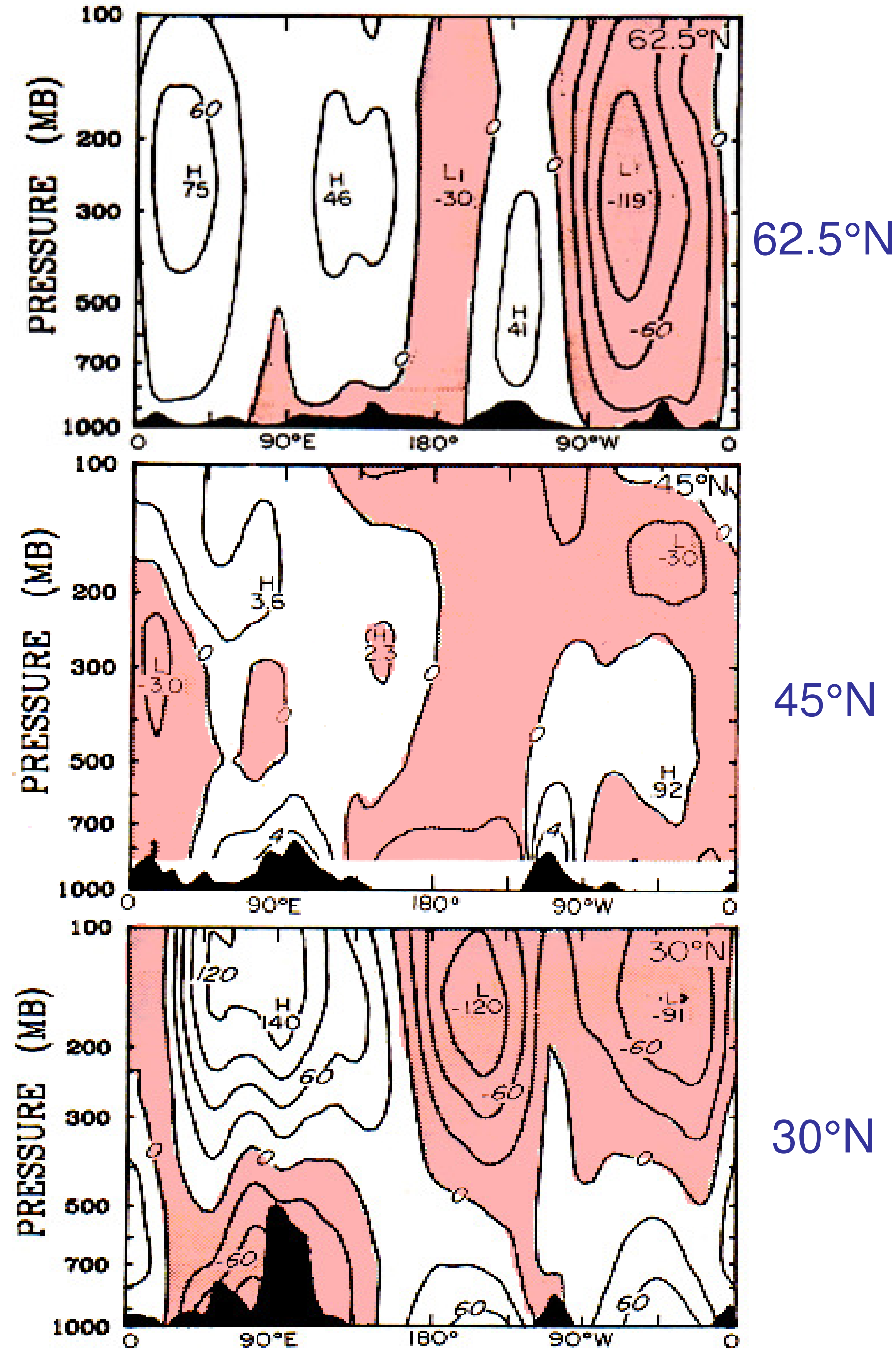
Background:

Summer stationary wave in the N. Hemisphere

Eddy geopotential height →

JJA

White (1982)

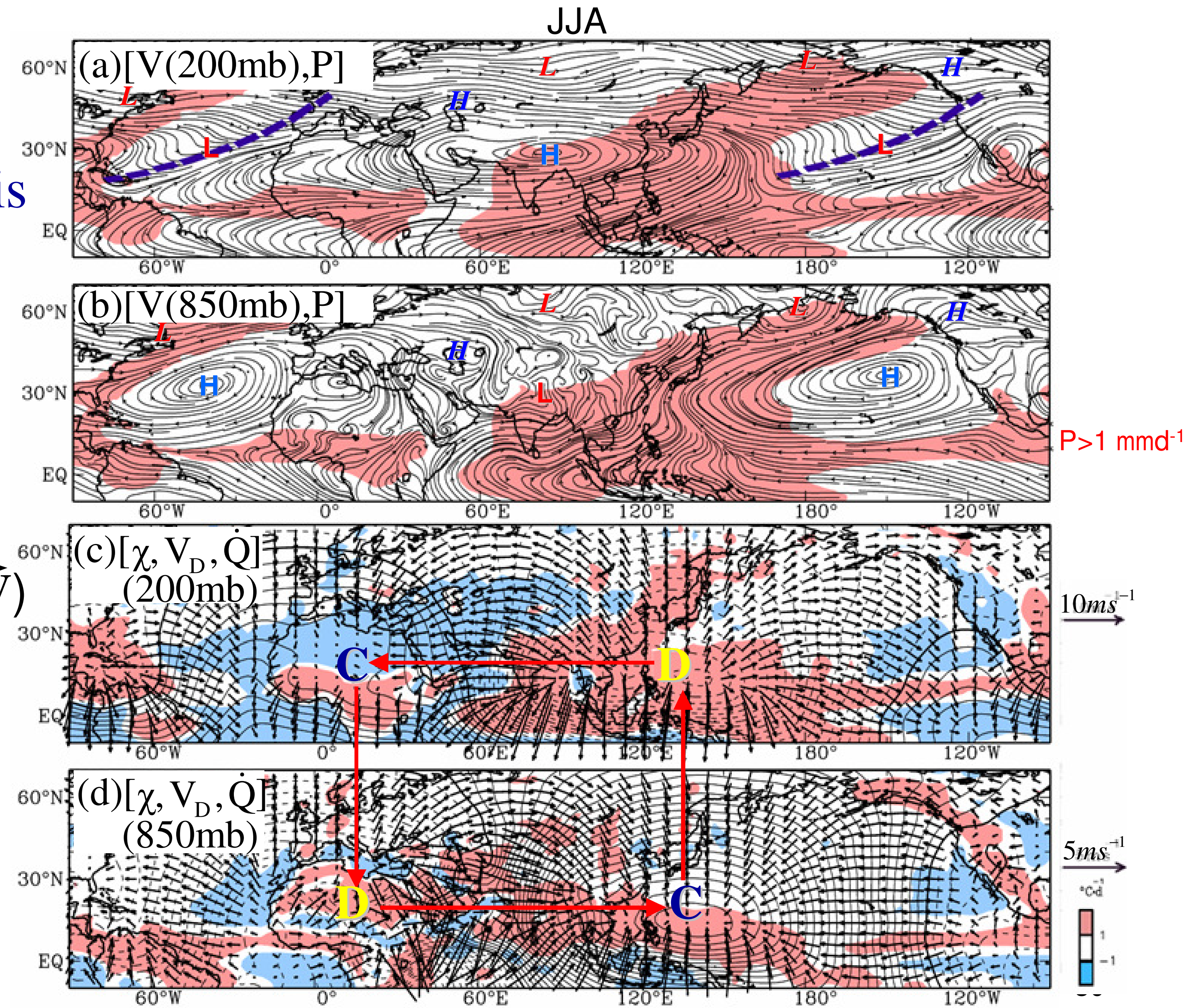


NCEP
Reanalysis

Velocity potential

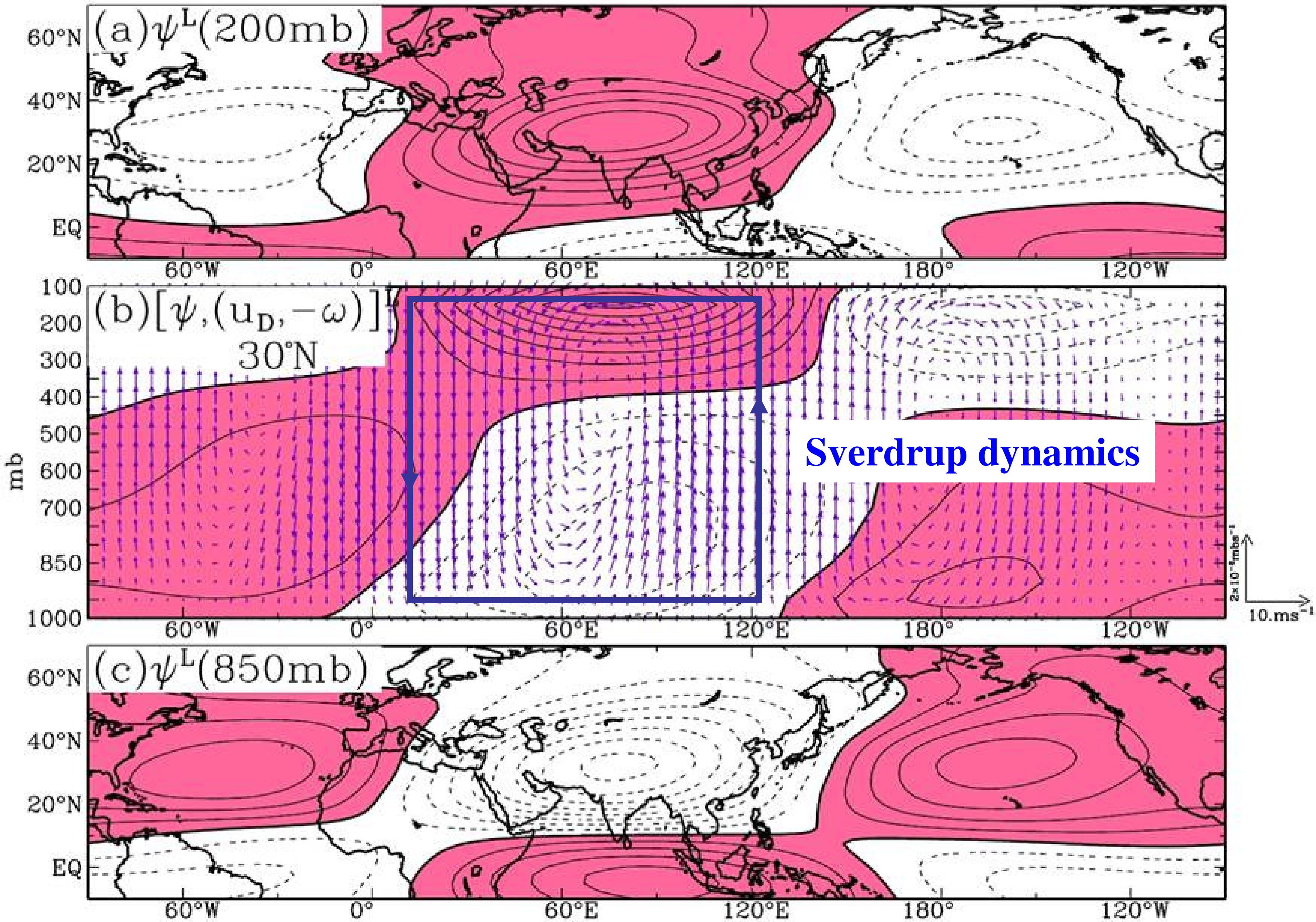
$$\chi = \nabla^{-2}(\nabla \cdot \vec{\mathbf{V}})$$

(Chen 2003)



Asian Monsoon (zonal wave # 1-2)

JJA



(Holton and Cotton 1972; Chen 2003)

Chen (2006)

(wintertime stationary wave)

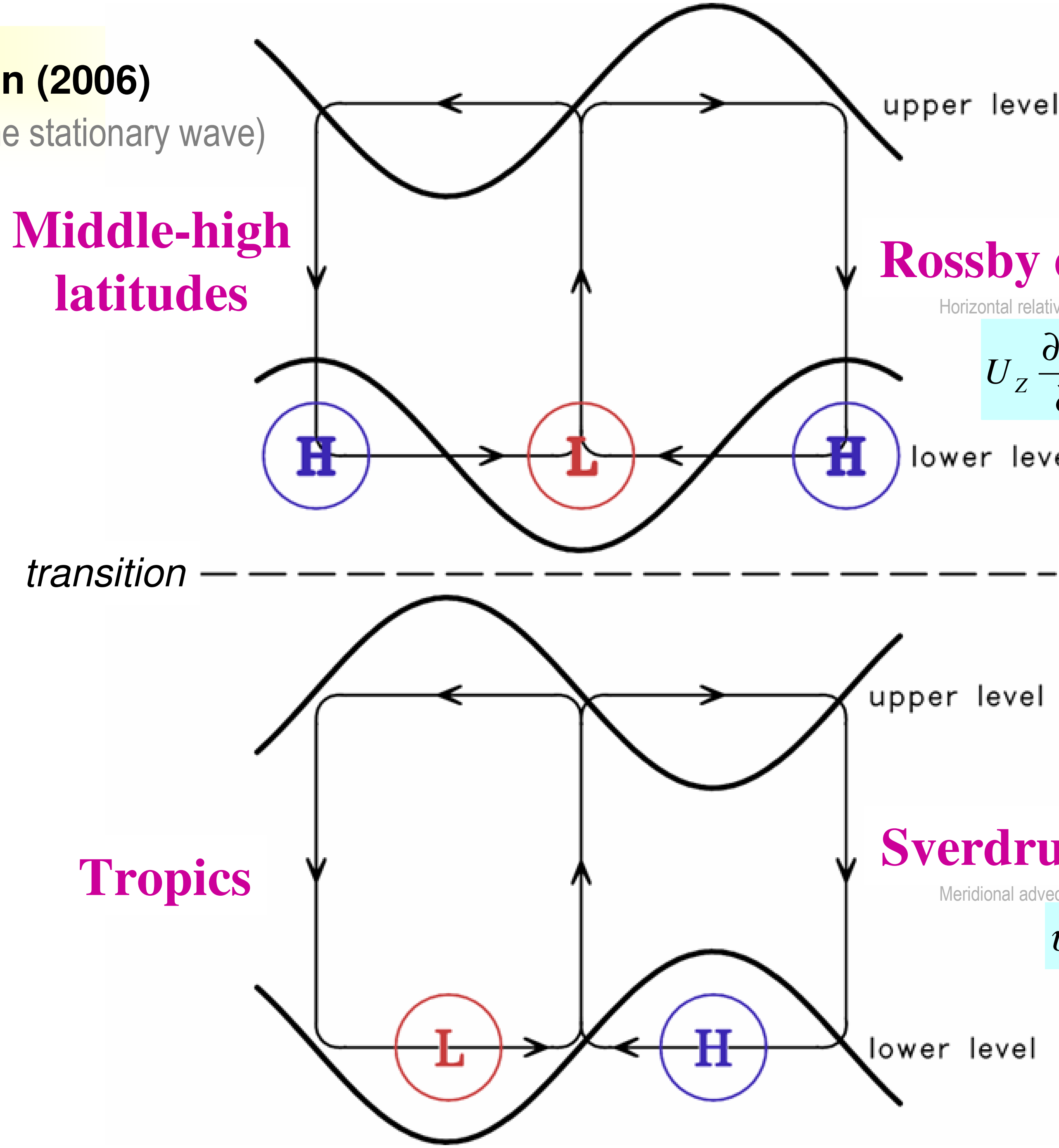
Middle-high latitudes

Rossby dynamics

Horizontal relative vorticity advection

$$U_Z \frac{\partial \zeta^n}{\partial x} + \upsilon^n \beta = -f\nabla \bullet V$$

$$0 \simeq -\mathbf{V} \bullet \nabla \mathbf{T} + \sigma\omega + \frac{1}{c_p}\dot{\mathbf{Q}}$$



Tropics

Sverdrup dynamics

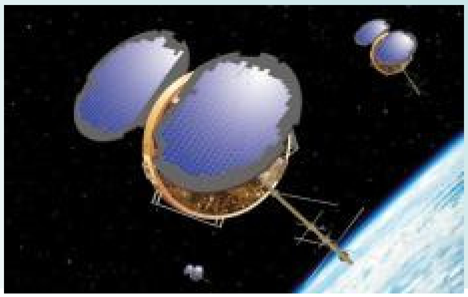
Meridional advection of planetary vorticity

$$\upsilon^n \beta = -f\nabla \bullet V$$

$$0 \simeq \sigma\omega + \frac{1}{c_p}\dot{\mathbf{Q}}$$

Assimilation experiment: June-July 2006

FORMOSAT-3/COSMIC



GPS RO
Z, T, q/RH

FIG. 1. Schematic diagram illustrating radio occultation of GPS signals. [Figure courtesy of NSPO.]

Anthes et al. (2008; BAMS)

Central Weather Bureau, Taiwan, Global Forecast System (CWB-GFS)

UCLA GCM (1st generation**)**
T-79, 18 levels (2nd generation)
OI → 3D Var global assimilation

June-July 2006 (00Z & 12Z)

Liou et al. (1997; *WAF*)

[No founding support; Goodwill research]

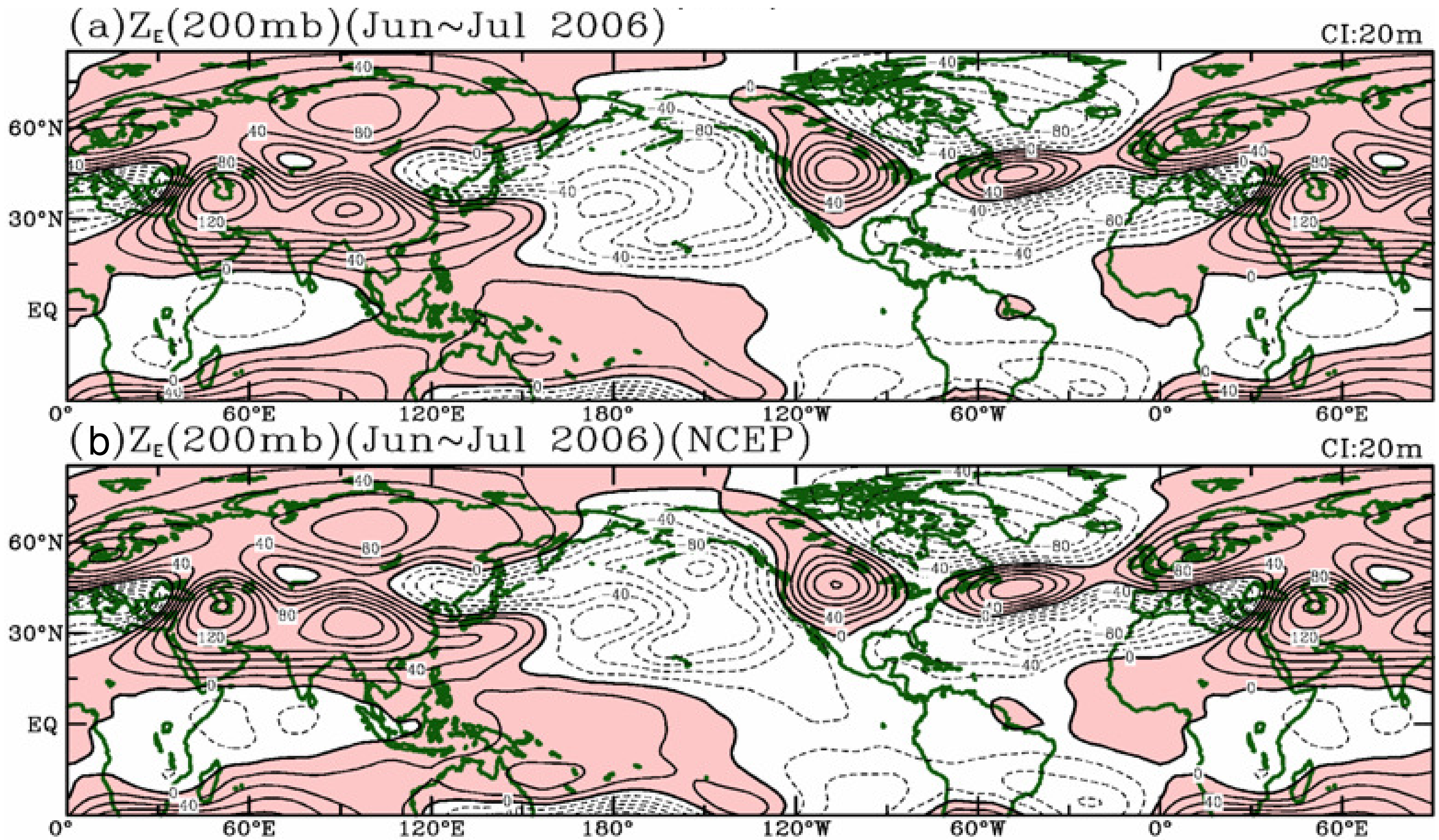
CWB-GFS *vs.* NCEP reanalysis

June & July 2006

CWB-GFS analysis

(200mb)

NCEP



$Var(|V|_{GFS}-|V|_{NCEP})/Var(|V|_{NCEP})=9\%$

CWB-GFS analysis agrees with the observation (NCEP)

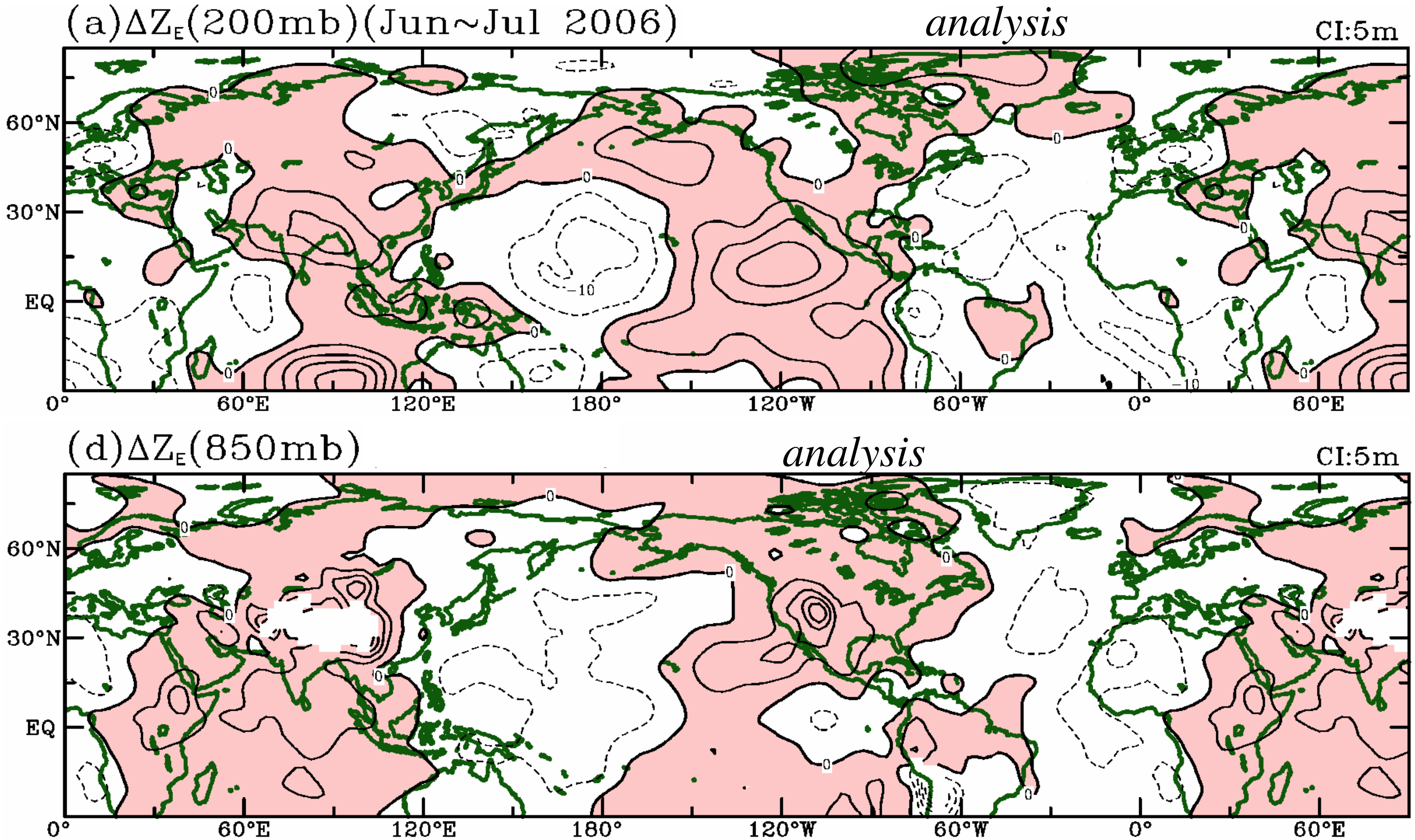
Impact of GPS assimilation on the CWB-GFS analysis fields

Preliminary results

Z_E

Anomalous circulation

GPS* – *Non·GPS



Var(%)=8

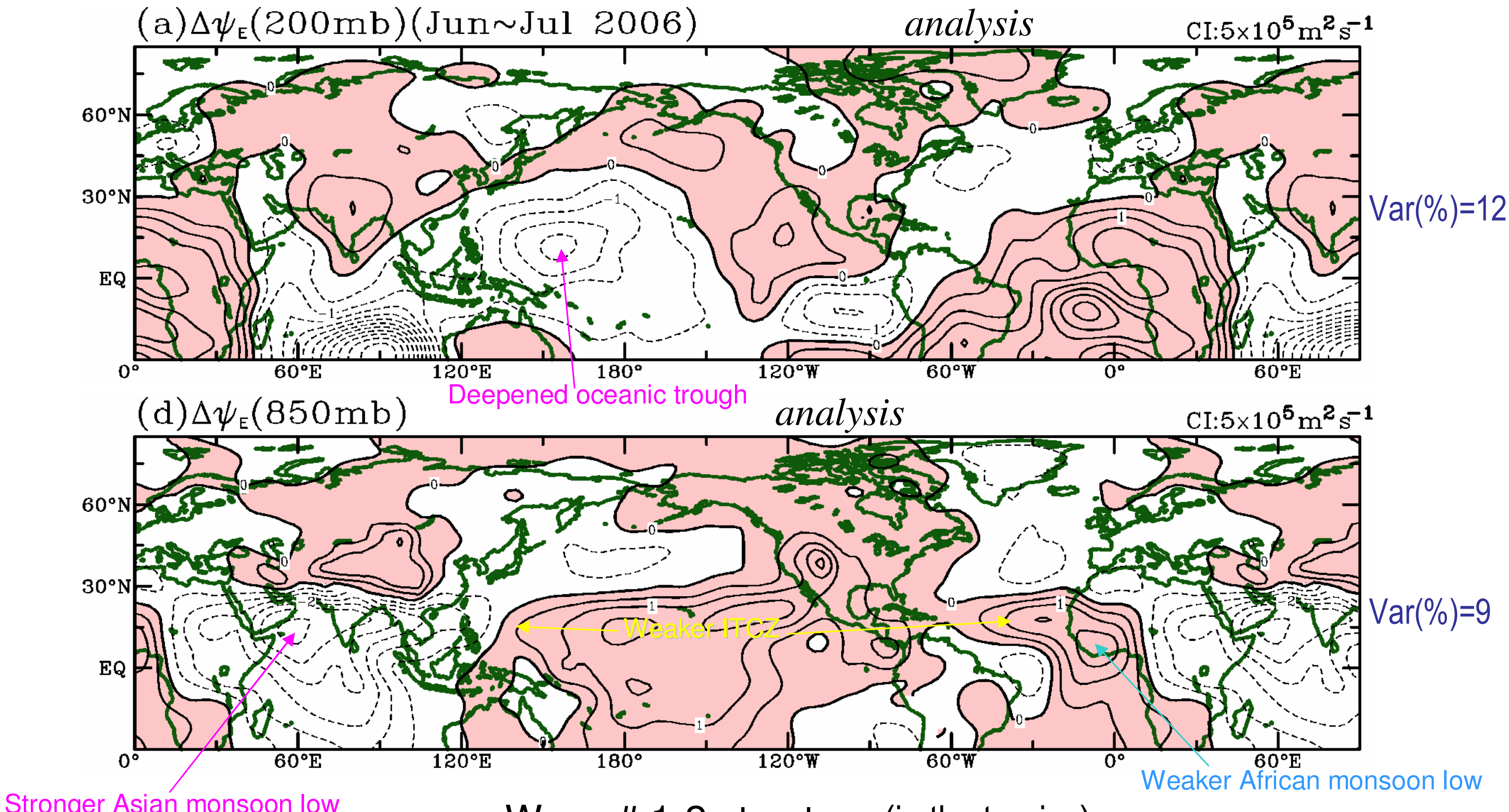
Var(%)=6

Wave # 2 structure

$$\psi_E = \nabla^{-2}(\vec{\nabla} \times \vec{v})_E$$

eddy

GPS* – *Non-GPS



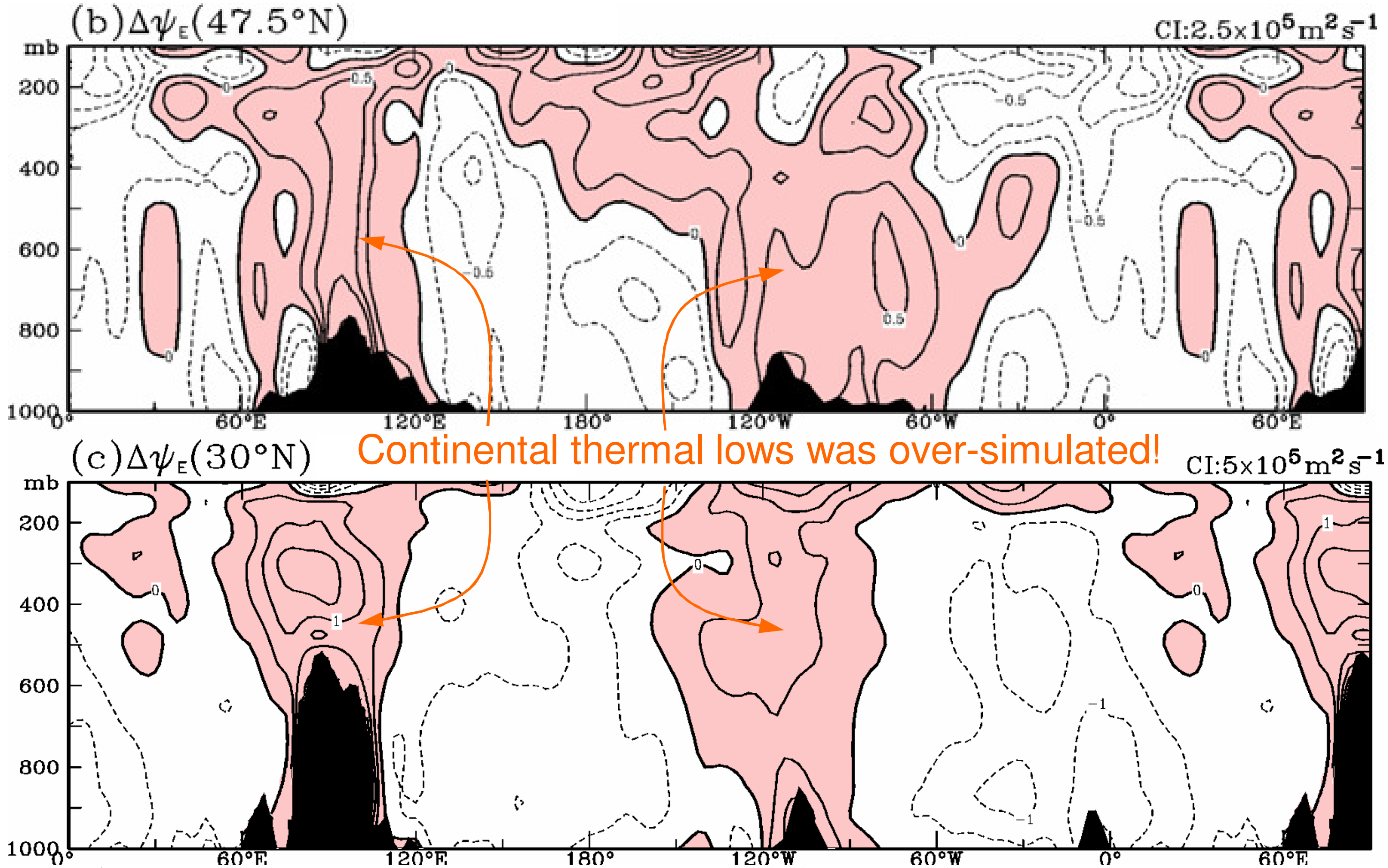
Wave # 1-2 structure (in the tropics)

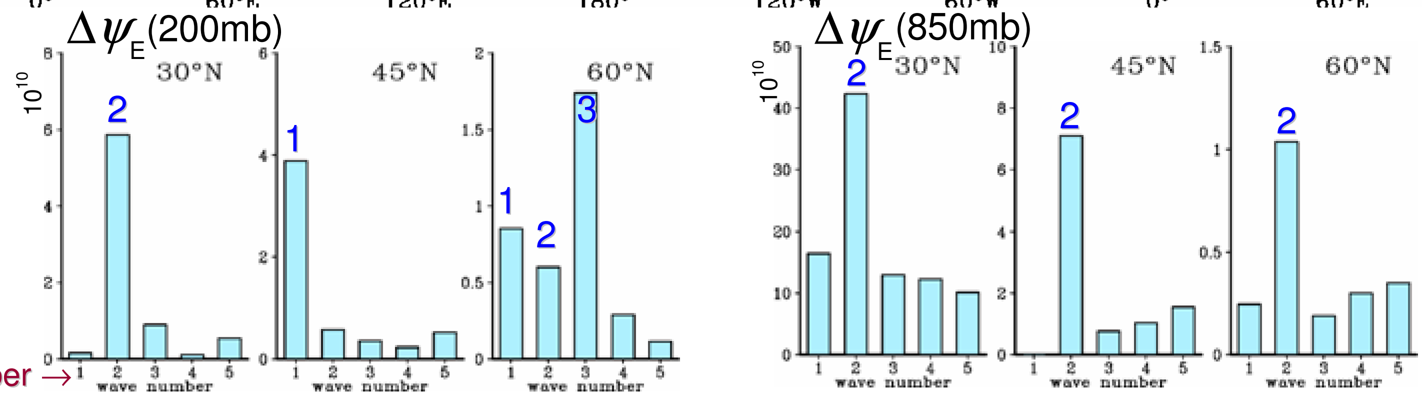
$\Delta\psi_E$ (vertical structure)

GPS – *Non-GPS*

47.5ºN

30ºN





Wave number →

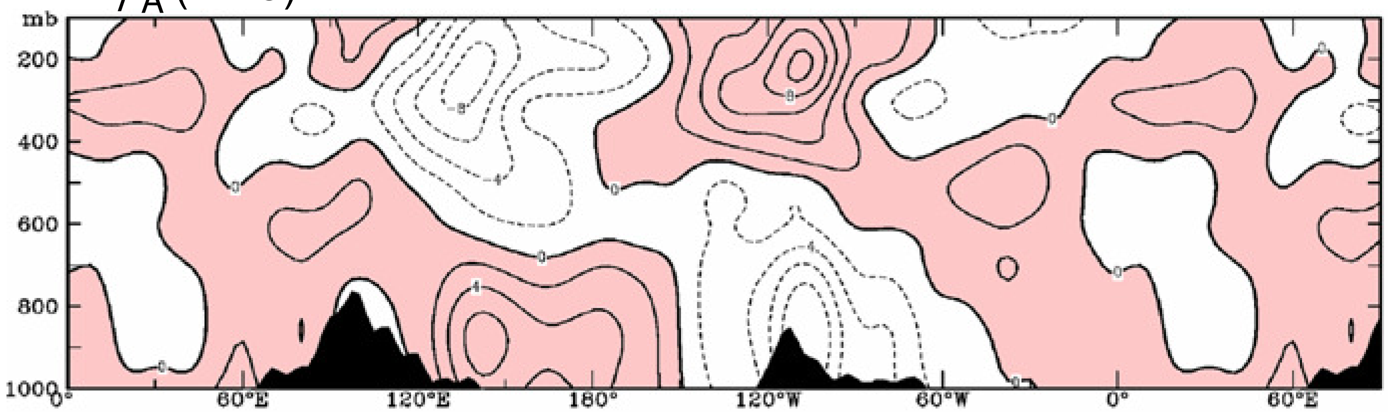
Spectral Streamfunction budget: (Chen and Chen 1990)

$$0 = \nabla^{-2}\left(-u_Z \frac{\partial \zeta^n}{\partial x}\right) + \nabla^{-2}\left(-\upsilon^n \beta\right) + \nabla^{-2}\left(-f\nabla \bullet V^n\right)$$

ψ^n_{A1} ψ^n_{A2} $\psi^n_{\chi 1}$

ψ_A (total vorticity advection) ψ_χ (total vortex stretching)

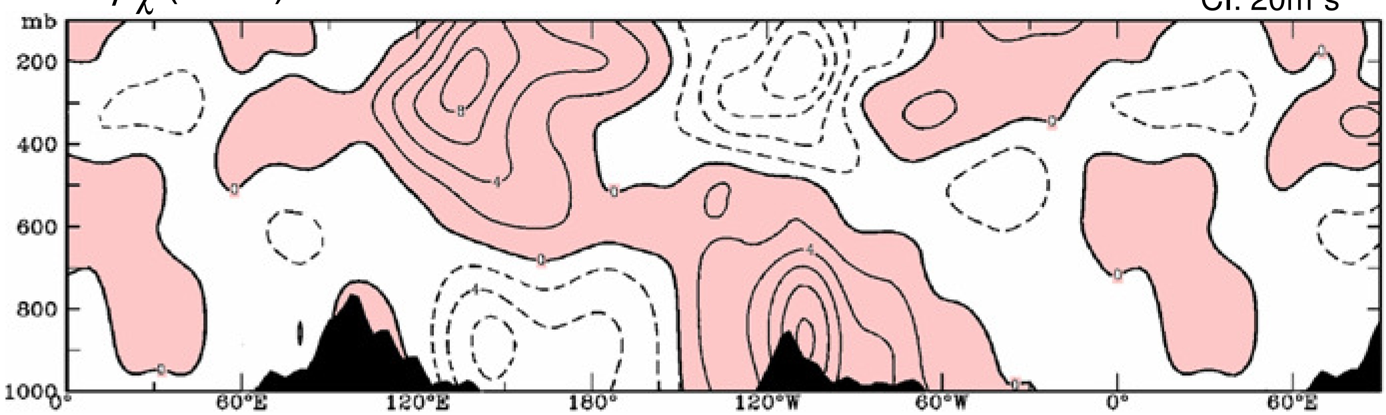
$\Delta\psi_A$ (47.5)



CI: $20 m^2 s^{-2}$

Cross-section $\Delta\psi_\chi$ (47.5) ***GPS* – *Non-GPS***

CI: $20 m^2 s^{-2}$



The anomalous circulation can be maintained —

Impact of FS-3 on the assimilation system is "*real*".

Velocity potential maintenance equation **(Chen & Yen 1991a,b):**

Heating:

$$\nabla\cdot\mathbf{V} = -\frac{\partial}{\partial p}\left[\frac{1}{\sigma}\left(\frac{\partial T}{\partial t}+\mathbf{V}\cdot\nabla T\right)\right]+\frac{\partial}{\partial p}\left(\frac{1}{\sigma c_p}\dot{Q}\right), \quad \chi=\nabla^{-2}(\nabla\cdot\mathbf{V})$$

$$\overline{\chi} = \underbrace{\nabla^{-2}\left[\frac{\partial}{\partial p}\left(\frac{-1}{\sigma}\overline{\mathbf{V}\cdot\nabla T}\right)\right]}_{\chi_H} + \underbrace{\nabla^{-2}\left[\frac{\partial}{\partial p}\left(\frac{1}{\sigma c_p}\dot{Q}\right)\right]}_{\chi_{\dot{Q}}}$$

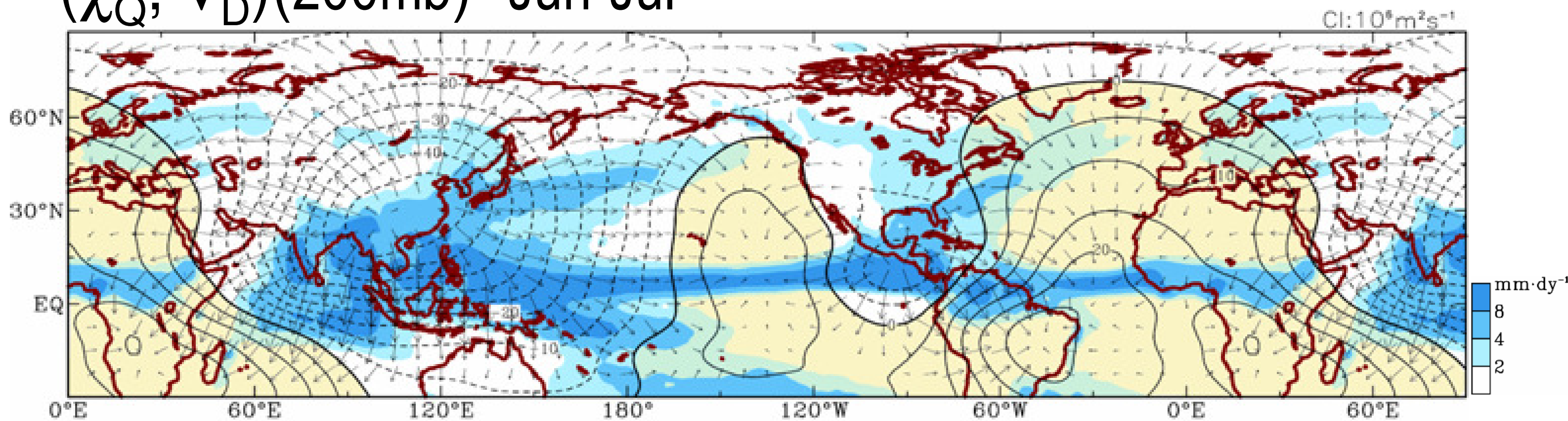
for stationary waves

(diabatic heating)

$(\chi_{\dot{Q}}, \mathbf{V}_D)$(200mb) Jun-Jul

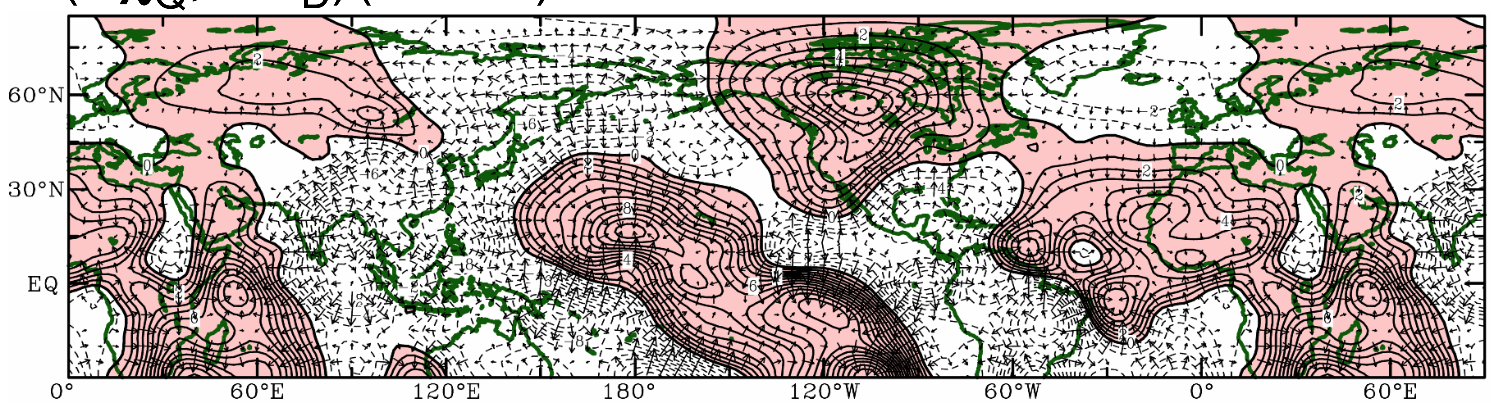
climatology

Deep convection
Diabatic heating



$(\Delta\chi_{\dot{Q}}, \Delta\mathbf{V}_D)$(200mb) *GPS* – *Non·GPS*

departure



Wave # 1-2 structure (in the tropics)

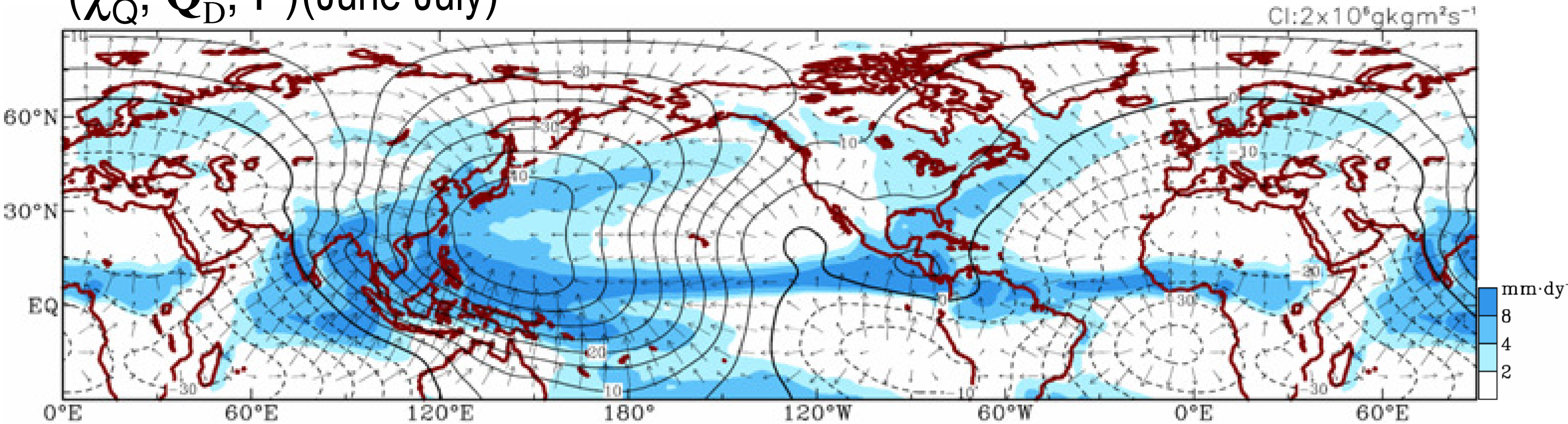
Moisture:

$$\vec{\mathbf{Q}} = \int_{p_S}^{0} (\mathbf{V} \cdot q)\, dp$$ *Vertically integrated water vapor flux*

$$\chi_Q = \nabla^{-2}(\nabla \cdot \vec{\mathbf{Q}}_D)$$ (Chen 1985)

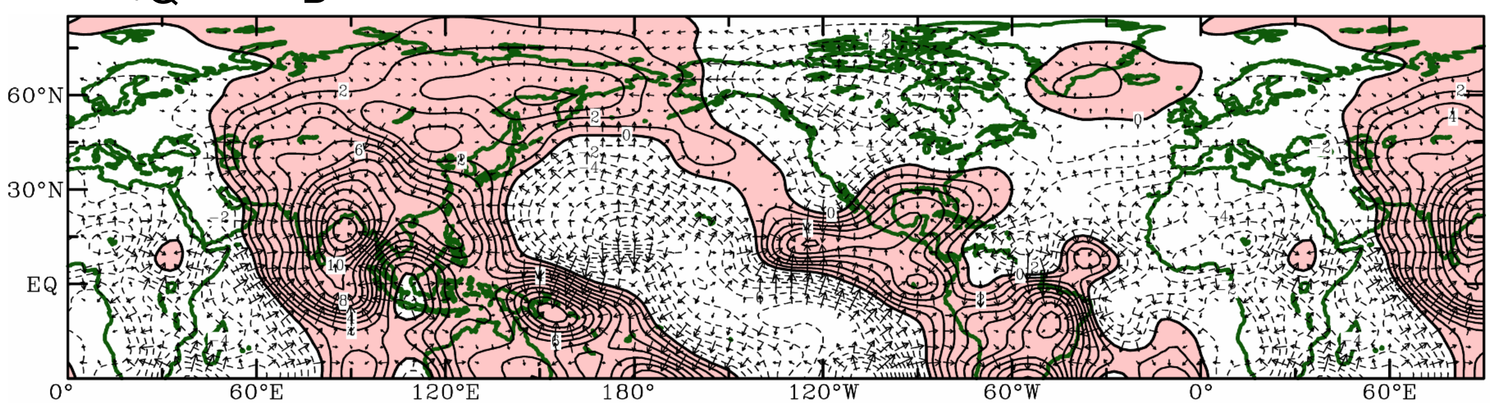
(χ_Q, $\mathbf{Q}_D$, P)(June-July)

climatology



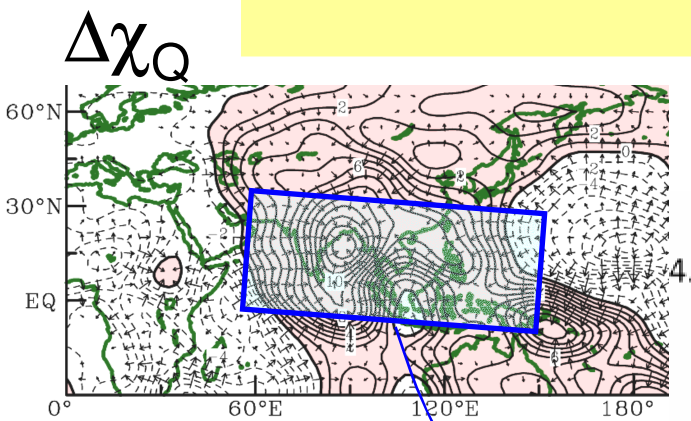
$\Delta\chi_Q$, ΔQ_D ***GPS – Non·GPS***

departure



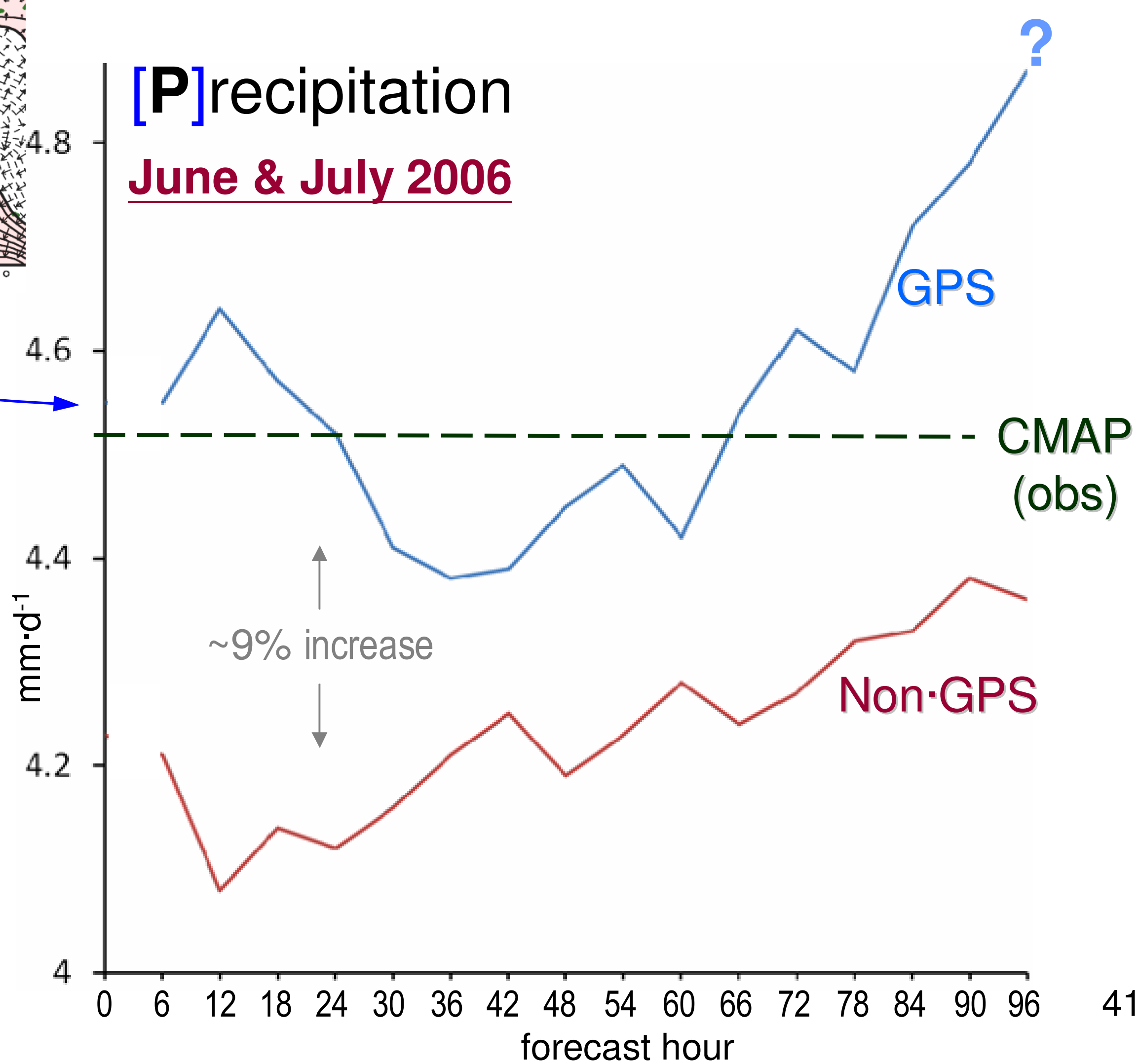
Wave # 1-2 structure (in the tropics)

Impact of GPS on CWB-GFS Precipitation forecast



Weather systems:

- Easterly waves
- Tropical storms
- Monsoon depressions
- Diurnal cycle



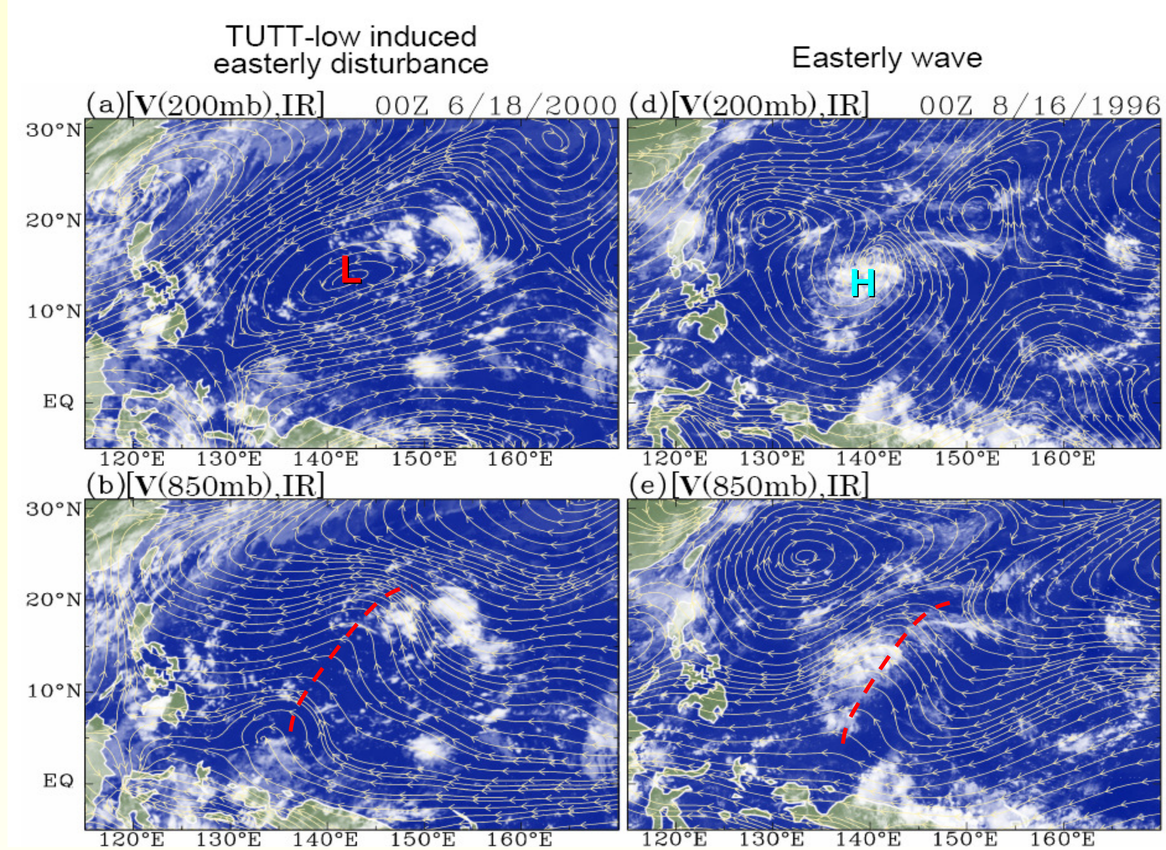
Applications

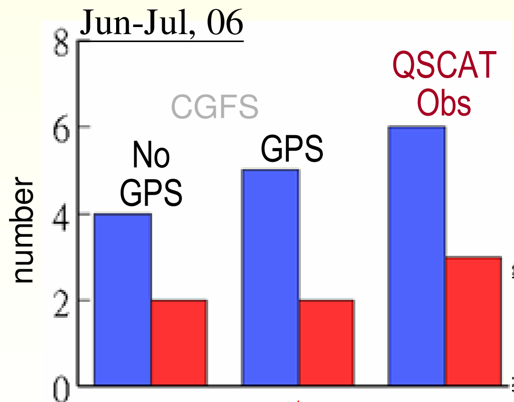
Impact of QSCAT on…

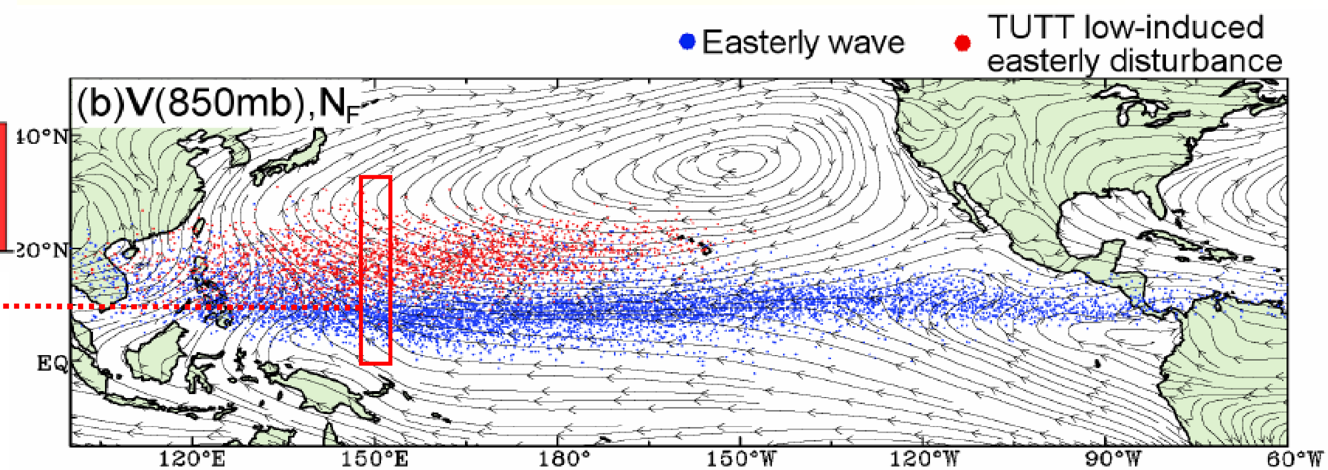
Easterly waves *vs.*
“false” easterly waves

Chen et al. (2008; MWR)

Tropical upper-tropospheric trough





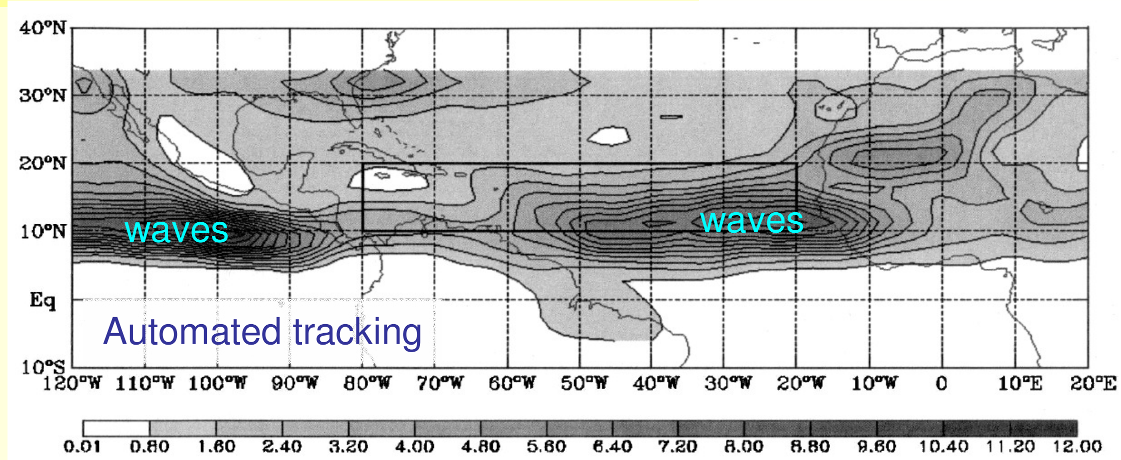


Applications

Impact of QSCAT on...

Hopsch et al. (2007; JCL)

African easterly wave frequency

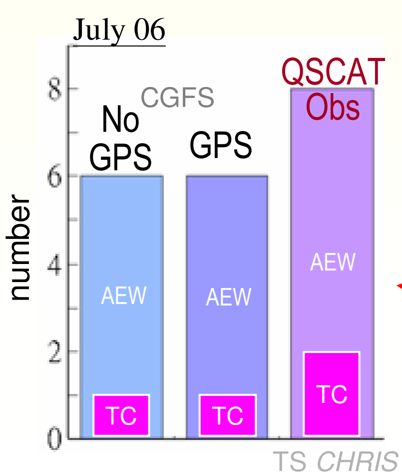


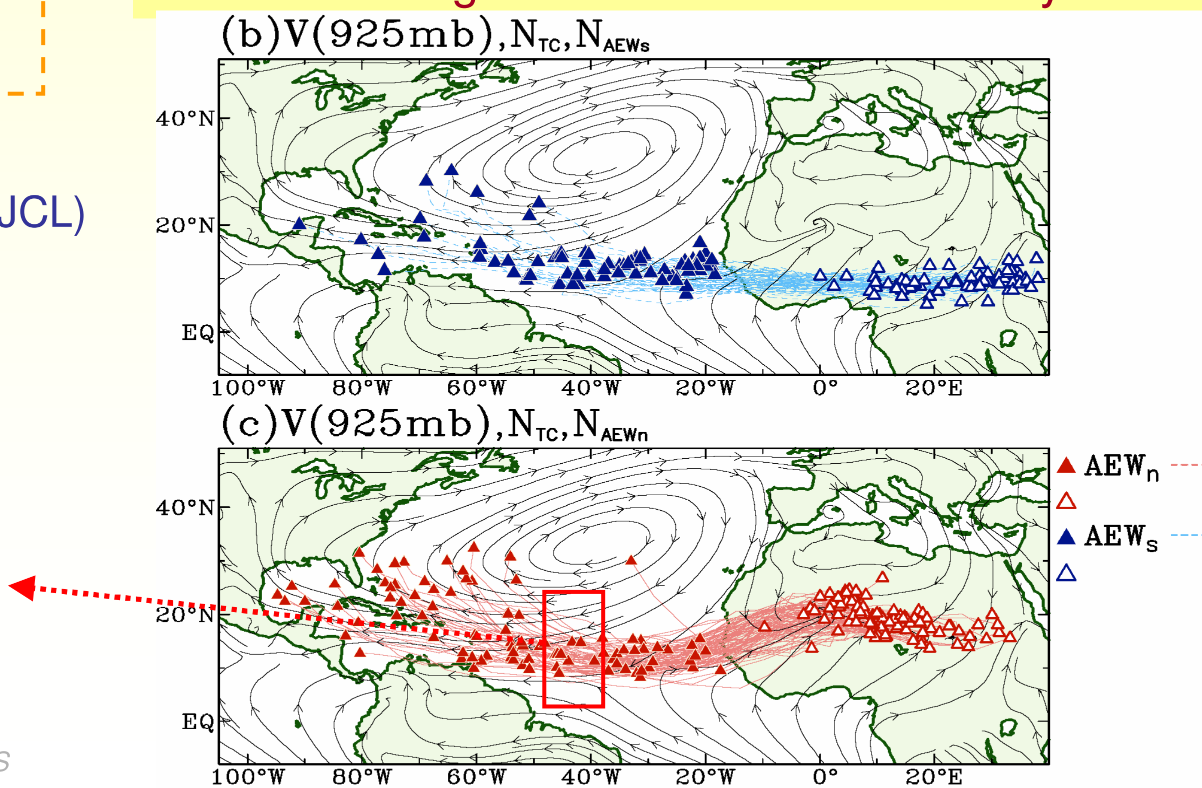
QSCAT on tropical cyclones:

- problematic signals in deep convection area
- TCs are already TCs; *what lead(s) to TCs?*

Hurricanes originated from African easterly waves

Chen et al. (2008; JCL)





Part-2 summary:

Assimilation of FORMOSAT-3/COSMIC reduces the overly simulated land-sea contrast in the global stationary waves.

Assimilation of FORMOSAT-3/COSMIC enhances the convergence of water vapor flux over the major monsoon regions and improves forecasted rainfall.

Future work:

Synoptic-scale tropical disturbances are the actual rain producer (and storm generator). Impact of GPS-RO or QSCAT assimilation on such disturbances needs to be investigated

Thank you!